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# ASSOCIATION OF SEED YIELD AND OIL CONTENT WITH OTHER CHARACTERS IN THE SUNFLOWER[1]

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The value in plant breeding of establishing association between characters, as an aid in selection of an invisible or difficultly measured character, through selecting an easily measured and associated character, is well recognized. In sunflowers this procedure is desirable in selection of material of high seed yield, as is the case with any grain crop, and it is also especially desirable in the selection of material of high oil content since the laboratory determination of oil content is a long and expensive test. This paper presents results of correlation studies measuring the association of seed yield and oil content with other plant and seed factors.

## MATERIALS AND METHODS

The material used in this study has consisted mainly of inbred lines of the Mennonite variety. These lines were established in 1937 from single head selections made in the district of Rosthern, Saskatchewan, in the previous year. In 1937 a small number of lines also were established from Russian introductions and in 1939 a second small group from Ottawa introductions were started. The first inbreeding of these lines at Saskatoon was done in the year they were established and they have been inbred each year since. The previous breeding history of the Russian and Ottawa lines is unknown. However, the Russian material was quite uniform from the start, so that presumably it had been inbred or closely selected for some time before it was received at Saskatoon. The Ottawa material was not as uniform as that from Russia but more so than the Mennonite material which had been grown under open pollination many years.

All material used in this study was grown in rows 3 feet apart with the plants spaced 3 feet apart in the row. With the exception of the single plant study and a few lines in 1939 when there were insufficient plants, all observations on height, head diameter and stem diameter were the average of 10 random plants of the line concerned. Stem diameter was measured at a point 6 inches above the soil level. Yield, except in the case of single plants, was computed by bulking the seed of each line and dividing by the number of plants from which seed was taken. This number ranged from 5 to 38 with the usual population being about 25. Lines were con-

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sidered mature when at least 50% of the plants were yellow in the head with the involucral bracts beginning to turn brown. Individual plants were considered mature when they had reached this stage. Determination of 1,000-seed weight was based on the average of three 100-seed samples. Percentage kernel was based on the separation of hull from kernel in a 5-gram sample. As a check the weight of both hull and kernel were added together with a deviation of ± 0.05 grams being the maximum error accepted. Oil percentage determinations, based on dry weight, were supplied by the Grain Research Laboratory, Winnipeg.

## RESULTS

### ASSOCIATION OF SEED YIELD WITH OTHER PLANT CHARACTERS

The associations of seed yield with a number of other plant characters as measured by the correlation coefficients are given in Table 1. Three groups of materials are indicated, the first comprising 188 Mennonite lines grown in 1938, the second group of 60 Mennonite lines grown in 1939 and the third, the same 1939 group but the observations being based on a single plant from each line.

TABLE 1.—CORRELATION COEFFICIENTS MEASURING ASSOCIATION OF SEED YIELD WITH OTHER PLANT CHARACTERS

188 Mennonite lines 1938

| Character | Simple coef. | Partial coef. | Multiple coef. |
|---|---|---|---|
| Days from seeding to maturity | .292† | .025 | |
| Height | .618† | .143 | |
| Stem diameter | .741† | .232† | |
| Head diameter | .769† | .469† | .821† |

60 Mennonite lines 1939

| Character | Simple coef. | Partial coef. | Multiple coef. |
|---|---|---|---|
| Days from seeding to maturity | .542† | .080 | |
| Height | .507† | .243 | |
| Stem diameter | .585† | .413† | |
| Head diameter | .557† | .195 | .773† |

60 Mennonite single plants 1939

| Character | Simple coef. | Partial coef. | Multiple coef. |
|---|---|---|---|
| Days from seeding to maturity | .342† | .062 | |
| Height | .392† | .094 | |
| Stem diameter | .251* | .369† | |
| Head diameter | .458† | .318* | .771† |

* Exceeds the 5% point.
† Exceeds the 1% point.

Considering the square of the multiple correlation (1) these data indicate that from 55 to 67% of the variability of yield is accounted for by the 4 factors, days from seeding to maturity, height, stem diameter and head diameter. All simple correlation coefficients, except that of yield with stem diameter for the single plants, exceed the 1% point. However, when the effect of the other variables is removed through calculation of the partial correlation coefficients, the values for the association of yield with maturity and yield with height, all drop below significant levels. In the case of the association of yield with stem diameter, the value, as shown by partial coefficient, remains above the highly significant level in the two cases and increases to exceed this level in the third case. In the case of the association of yield with head diameter, a highly significant value remains for 1938 and a significant one for the single plants in 1939, but that for the Mennonite lines in 1939 drops below the 5% point.

None of the differences in the coefficients as calculated from the 60 individual plants and from the same observation based on the average of 10 plants in each line is significant as tested by the statistic $z$. (Fisher cit. 1). This indicates there is no difference between the association of characters on a single plant basis and the association when a group of plants are averaged in one line for measurement of the characters. However, the characters of a line could probably be more reliably studied through the average of a number of plants, in spite of this result.

That such a marked association between yield and stem diameter should be indicated is surprising. It would be expected that the association between yield and head diameter would be the greatest. Actually this is so in the 1938 material and the relatively large coefficient of .469 in this case probably has more significance than that for the 1939 material since it is based on a much larger number of lines. However, the 1939 results of yield with head diameter tend to agree with those of Ross (2) who failed to find a significant positive relationship for these characters in his studies. In the case of yield and height he obtained a simple coefficient exceeding 1% point, which is in agreement with the results reported here. Ross does not report any partial coefficients so it is not known if this relationship would have dropped below the significant level had the effect of the other factors been removed as was the case with the results at Saskatoon. It is also worthy of note that Ross found a negative coefficient between yield and days from seeding to blooming which exceeded the 1% point. Days from seeding to blooming would likely be closely related to days from seeding to maturity, in which case his results are much different from the significant positive correlations between yield and maturity shown in Table 1.

## ASSOCIATION OF OIL CONTENT WITH SEED AND PLANT CHARACTERS

In studying the relationship of oil content with other factors Ross (2) noted a positive correlation exceeding the 1% point between oil content and yield. Scheibe's data (3) indicate that the larger seed sizes usually gave the lowest percentage of oil but the highest absolute content of oil per seed. The reverse, that smaller seed sizes gave the highest percentage

of oil, does not appear to hold in Scheibe's data. Table 2 provides the simple correlation coefficients for 3 years data taken at Saskatoon from 3 different types of material correlating percentage of oil with yield, percentage of kernel, 1,000-kernel weight and weight per bushel.

TABLE 2.—SIMPLE CORRELATION COEFFICIENTS MEASURING ASSOCIATION OF OIL CONTENT WITH OTHER FACTORS

| Factor | | Material | | | |
|---|---|---|---|---|---|
| | | Russian lines | Mennonite lines | Ottawa lines | All lines |
| | No. of lines | 7 | 82 | | 89 |
| Yield | 1938 | .326 | .147 | | .126 |
| % kernel | 1938 | .533 | .550† | | .507† |
| 1000-seed weight | 1938 | −.204 | −.073 | | −.138 |
| | No. of lines | 6 | 29 | 10 | 45 |
| Yield | 1939 | .090 | −.009 | .016 | |
| % kernel | 1939 | .032 | .830† | .807† | .726† |
| 1000-seed weight | 1939 | .492 | −.350 | −.174 | −.370* |
| Weight per bus. | 1939 | −.018 | .127 | .369 | .284 |
| | No. of lines | 11 | 14 | 5 | 30 |
| Yield | 1940 | .263 | .140 | .111 | .524 |
| % kernel | 1940 | .430 | .900† | .893* | .783† |
| 1000-seed weight | 1940 | −.145 | −.121 | −.235 | −.350 |
| Weight per bus. | 1940 | .523 | .287 | .933* | .642† |

* Exceeds the 5% point.
† Exceeds the 1% point.

From Table 2 the only factor which appears to have any definite relationship with oil content is percentage kernel. In 8 out of 11 cases the coefficient measuring this association exceeds the 5% point, and in 7 of these, it exceeds the 1% point. While this is the only relationship of importance, the tendencies shown by the other coefficients of the table are of interest. Thus there is a slight positive association between yield and oil content indicated in most cases as well as between oil content and weight per bushel, the coefficient even exceeding the 1% point in one case and the 5% in another. Since small seed is desirable in order to avoid hulling and seed breakage by harvesting machinery, the slight negative relationship between percentage oil and seed size indicated that this objective, combined with high oil content could easily be attained in breeding.

In addition to the data which are presented in Table 2, a more detailed study was made of 82 Mennonite lines of year 1938, considering the relationship of oil content with the plant characters referred to in Table 1, and the seed characters in Table 2. The results of this study are given in Table 3.

TABLE 3.—CORRELATION COEFFICIENTS MEASURING THE ASSOCIATION OF PERCENTAGE OIL WITH OTHER PLANT AND SEED CHARACTERS IN 82 MENNONITE LINES OF YEAR 1938

| Factor | Simple | Partial | Multiple |
|---|---|---|---|
| Days to mature | .167 | | |
| Height | .077 | | |
| Stem diameter | .156 | | |
| Head diameter | .129 | | |
| Seed yield | .146 | | |
| 1000-seed weight | −.073 | | |
| % kernel | .550* | .519* | .599* |

* Exceeds the 1% point.

The results given in Table 3 verify the main conclusion from Table 2, namely, that there is a definite positive association between the oil content and kernel content of the seed. Considering the square of the multiple coefficient, the 7 factors in Table 3 account for about 36% of the variability in the oil percentage and of this 31% is accounted for by the association of oil content with kernel content. This rather low variability accounted for by these factors also shows that many others must be concerned in determining oil content.

## ASSOCIATION OF KERNEL CONTENT WITH SEED SIZE

Since the data of Table 2 indicate a strong positive association between oil content and kernel content but a negative relationship between oil content and seed size it is of interest to know the association of kernel content and seed size. Results of studies determining this are presented in Table 4.

TABLE 4.—SIMPLE CORRELATION COEFFICIENTS MEASURING ASSOCIATION OF KERNEL CONTENT WITH SEED SIZE

| Year | 1938 | | 1939 | | 1940 | |
|---|---|---|---|---|---|---|
| Material | No. of lines | $r$ | No. of lines | $r$ | No. of lines | $r$ |
| Russian | 7 | −.648 | 6 | .085 | 11 | .611 |
| Mennonite | 141 | −.155 | 73 | −412* | 14 | .180 |
| Ottawa | | | 10 | −.192 | 5 | −.250 |
| All lines | 148 | −.259* | 89 | −.418* | 30 | −.266 |

* Exceeds 1% point.

In 9 out of the 11 cases in this table a negative correlation between percentage kernel and seed size is shown and in 3 of these cases the coefficient exceeds the 1% point. These results can be taken as favoring selection of small seeded lines to secure material of high kernel content.

## ASSOCIATION OF YIELD WITH SEED SIZE

The data presented in previous tables favors the selection of material of small seed size. In Table 5 are presented the simple correlation coefficients measuring the association of seed size with seed yield.

TABLE 5.—SIMPLE CORRELATION COEFFICIENTS MEASURING ASSOCIATION OF YIELD WITH SEED SIZE

| Year | 1938 | | 1939 | | 1940 | |
|---|---|---|---|---|---|---|
| Material | No. of lines | $r$ | No. of lines | $r$ | No. of lines | $r$ |
| Russian | 7 | .032 | 6 | −.712 | 11 | .300 |
| Mennonite | 141 | .376* | 73 | .199 | 14 | −.090 |
| Ottawa | | | 10 | .499 | 5 | .148 |
| All lines | 148 | .349* | 89 | .232 | 30 | .023 |

* Exceeds 1% point.

In two cases there is a highly significant positive correlation between yield and seed size shown in Table 5. In 7 out of the other 9 cases a positive relationship is also shown, thus indicating that there is greater possibility of securing high yielding lines in the large seeded material than in small seeded material.

## CONCLUSIONS

The correlation studies reported in this paper indicate that selection for large heads and large stems will aid materially in the procuring of lines of high seed yield and selection for high kernel content will aid greatly in procuring lines of high oil content. They also show that the selection of material with short stems and early maturity, which is desired in a type suitable for harvesting with a combine, will not deter the attainment of high yielding lines. There are indications that small seed size, which is being selected in order to avoid damage to the seed in threshing, also will aid in securing lines of high oil content, because there is a small negative correlation between seed size and oil content and between seed size and kernel content, which is closely associated with oil content. On the other hand there is just as strong a positive correlation between seed yield and seed size so that if yield is to be maintained a small seed size should be avoided unless it has a very high oil content. In selecting for seed size it would be well to keep both these factors in mind with the object of choosing that material which will give the greatest oil yield, rather than that which will provide the greatest seed yield or oil content alone.

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## SUMMARY

1. The results of correlation studies over 3 years with sunflowers to establish associations of seed yield and oil content of the seed with other plant and seed characters are reported.

2. The 4 factors, days from seeding to maturity, height, head diameter, and stem diameter, gave multiple correlations with yield of between $r = .711$ and $r = .821$ or accounted for 55 to 67% of the variability of yield. All simple correlation coefficients between yield and these factors were positive and highly significant. In the partial coefficients, days from seeding to maturity and height dropped below the 5% point, stem diameter remained above the 1% point, in all cases, and head diameter in 2 cases out of 3.

3. The 5 factors mentioned under (2) together with percentage kernel and weight per 1,000 seeds gave a multiple correlation of $r = .559$ with oil content, or accounted for only 36% of the variability. Of this, 31% was accounted for by the relationship of oil content with kernel content as shown, by the highly significant partial correlation coefficient of .519 between these 2 factors.

4. Slight negative correlations were found between oil content and seed size and between kernel content and seed size.

5. Slight positive correlations were found between oil content and seed yield and between seed yield and seed size.

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# THE INFLUENCE OF VARIOUS CULTURAL PRACTICES ON SEED AND PLANT CHARACTERS IN THE SUNFLOWER[1]

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In 1937 a breeding program was commenced at Saskatoon with the object of developing sunflower strains of early maturity with high seed yield and possessing high oil content in the seed. At that time little information was available on methods of growing and handling the seed crop. Farmers in Western Canada had not grown sunflowers for seed extensively and there were no references to investigational studies concerning seed production in the available literature. Consequently, it was desirable to conduct studies for determining the effect of various cultural practices on seed yield and other factors. The data secured have shown that variations in date of seeding, plant spacing in the row, and date of harvest have a marked effect on seed yield, and oil content of the seed as well as other seed and plant characters. It is the purpose of this paper to present the results of these cultural studies.

## MATERIALS AND METHODS

In all tests, the seed was sown about 2 inches deep with a Columbia hand seeder. The rows were spaced 3 feet apart with the plant spacing in the row varying with the test, the desired spacing being secured by thinning after emergence. Maturity was considered as that stage when approximately 50% of the plants were yellow on the back of the head with the involucral bracts turning brown. Threshing was done with a simple sunflower thresher constructed after that described by Scheibe (2). After threshing and air drying, except in the date of harvest test, the seed was cleaned in a small "Clipper" mill and the weight of clean seed secured, used in calculation of yield per acre.

In all studies the 1000-seed weight determinations were based on 3 100-seed samples. The percentage kernel determinations were based on the separation of hull from kernel in a 5-gram sample. As a check the hull and kernel were both weighed and added together with a deviation of $\pm$ 0.05 grams being the maximum discrepancy accepted. Oil analyses were based on the dry weight of the whole seed. They were supplied by the Grain Research Laboratory, Winnipeg, until 1941, when they were provided by the Oil Seeds Laboratory, University of Saskatchewan, Saskatoon.

### DATE OF SEEDING TEST

This test, to study the effect of various seeding dates, was conducted for three years with seed of the Mennonite variety. This is a short heterogeneous type grown by Mennonite farmers in various districts of Western

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Canada. Six dates of seeding at 10-day intervals, starting April 20, were used. Each year the test was conducted in a randomized block arrangement with 4 replicates. Plots consisting of 4 rows, 20 feet long, with plants 3 feet apart in the row were used in 1937 and 1938. In 1939 the plot size was modified to 3 rows and the plant spacing reduced to 2 feet.

### PLANT SPACING TEST

A test to study the effect of various plant spacings in the row has been conducted over a period of 5 years from 1937 to 1941. In the first 3 years only Mennonite material was used. Six spacings, from 6 inches to 36 inches, increasing with 6-inch increments were studied. The number of replicates, plot size and arrangement were the same as described for the date of seeding test.

In 1940 this test was modified by including another strain and using only the 6, 18 and 36-inch spacings. A split plot design with 6 replicates was employed with the strains constituting the main plots and the spacings the subplots. The subplots consisted of 3 rows, 20 feet long. The second strain, designated S-490, is a relatively small seeded single stem type, introduced from Russia. Bulk open pollinated seed of this strain from the breeding nursery was used in the test so that this material would largely be hybrid in nature.

### DATE OF HARVEST TEST

The date of harvest test has been conducted in the 3 years 1939 to 1941 with bulk Mennonite seed similar to that used in the date of seeding test. The plots consisted of 3 rows, 20 feet long, with the plants spaced 2 feet apart in the row. The test was conducted in a randomized block design of 4 replicates with 6 dates of harvest, the first on September 1 and the others at subsequent 10-day intervals.

Immediately after the seed had been threshed it was passed through a "Clipper" fanning mill and then weighed. It was felt that this treatment would clean the seed to a condition comparable with that obtained by harvesting with a combine. In 1939, after being weighed, the seed from the first 3 dates of harvest was wrapped in several thicknesses of newspaper in an effort to reduce air circulation and thus produce storage conditions similar to those in a large bin. After 6 to 8 weeks the packages were opened, examined for evidence of spoiling and allowed to air dry, then re-weighed to determine the amount of moisture lost. They were then recleaned to remove trash which had been too moist to take out in the first cleaning, and the weight of seed remaining used to calculate the yields per acre. The 1940 and 1941 tests were handled in the same manner, except that the seed from each plot was stored in a metal can 6 inches in diameter and $9\frac{3}{4}$ inches high with the cover sealed on by adhesive tape. It was felt such treatment would approach the storage condition of a bin better than wrapping in newspaper.

## RESULTS

### DATE OF SEEDING TEST

*Seed Yield*

A summary of the data for seed yield from the date of seeding test for the 3 years 1937, 1939 and 1940 is presented in Table 1. No data for

1938 are included because damage by gophers in the early stages made the results of that year unreliable.

TABLE 1.—INFLUENCE OF DATE OF SEEDING ON THE SEED YIELD* OF THE MENNONITE VARIETY

| Seeding date | 1937 | 1939 | 1940 | Average |
|---|---|---|---|---|
| | lb. | lb. | lb. | lb. |
| April 20 | 326 | 1,055 | 770 | 717.0 |
| May 1 | 248 | 1,199 | 658 | 701.7 |
| May 10 | 200 | 1,346 | 680 | 742.0 |
| May 20 | 234 | 1,435 | 939 | 869.3 |
| June 1 | 134 | 1,274 | 482 | 630.0 |
| June 10 | 154 | 728 | 328 | 403.3 |
| Average | 216.0 | 1,172.8 | 642.8 | |

* Yield in pounds per acre.

Variance Analysis

| Source | *D.F.* | Sum of Squares | Variance | *F* |
|---|---|---|---|---|
| Years | 2 | 11,030,779 | 5,515,390 | 370.06† |
| Replicates | 3 | 54,618 | 18,206 | 1.22 |
| Replicates × Years | 6 | 85,014 | 14,169 | — |
| Dates | 5 | 1,447,400 | 289,480 | 19.42† |
| Dates × Years | 10 | 858,728 | 85,873 | 5.76† |
| Error | 45 | 670,666 | 14,904 | |
| Total | 71 | 14,147,205 | | |

† Exceeds 1% point.

Necessary difference for dates, 19 : 1 odds = 100.2 lb.
Necessary difference for dates, 99 : 1 odds = 133.7 lb.
Necessary difference for years, 19 : 1 odds = 70.8 lb.
Necessary difference for years, 99 : 1 odds = 94.4 lb.

The data presented in Table 1 show the yield of seed secured from the May 20 date of seeding, as an average of the 3 years, exceeds all others, the difference being highly significant in all cases. It is also clearly shown that low yields are obtained from the late dates of seeding. The difference between the June 10 date and the other dates, for the 3-year average, is highly significant in all cases, while that between the June 1 date and the earlier dates is highly significant in one case, significant in another and approaches significance in the other two. Examining the differences between years it is seen that they are all highly significant.

The variance analysis shows a highly significant interaction between dates and years. This is probably largely brought about by the April 20 date in 1937 being the highest yielding and the June 1 date in 1939 being

relatively high yielding. In 1937 there was unusually low precipitation in June and July but about normal in April and May which would favour the earliest date of seeding. A somewhat opposite condition in 1939, of low early spring rainfall and high June rainfall probably accounts for the high yield of the later dates in that year. In spite of this interaction, however, comparing the variance of dates with dates × years gives an $F$ value of 3.37 which exceeds the 5% point and shows that some dates did yield higher than others as an average in the 3 years studied.

*Days from Seeding to Maturity*

Table 2 presents a summary of the number of days required from seeding to maturity for the 6 different dates in the years 1937, 1939 and 1940.

TABLE 2.—NUMBER OF DAYS FROM SEEDING TO MATURITY FOR DIFFERENT DATES OF SEEDING

| Seeding date | 1937 | 1939 | 1940 | Average |
|---|---|---|---|---|
| April 20 | 125 | 132 | 134 | 130.3 |
| May 1 | 120 | 131 | 125 | 125.3 |
| May 10 | 110 | 125 | 119 | 118.0 |
| May 20 | 109 | 125 | 109 | 114.3 |
| June 1 | 105 | 121 | 107 | 111.0 |
| June 10 | 100 | 116 | 103 | 106.3 |
| Average | 115.5 | 125.2 | 116.6 | |

The data in this table show that while the later dates do not require as long to mature as the earlier ones, the time gained in a more rapid maturity does not make up for the time lost in the spring. For example, considering the average for the 3 years, the May 20 date, seeded 30 days later than the April 20 date, only required 16 days less to mature, or was 14 days later than the April 20 date in maturity. Similarly, the May 20 date was 6 days later in maturing than the May 10 date.

On the basis of the data presented in Tables 1 and 2 it should be stressed that no later date of seeding than May 20 should be used for two reasons. First, as is shown in Table 1 there is a definite tendency for the later dates to give low yields, and second, any later date would likely fail to mature and dry sufficiently for harvesting with a combine. In fact it may be advisable to seed earlier than May 20 and sacrifice some yield to ensure proper maturity.

It is worthy of note that this emphasis on seeding early is more with the object of drying the crop sufficiently for harvesting with a combine than to avoid damage to the seed by early frost. An early killing frost might even be welcomed as it would destroy the leaves, stopping any further movement of moisture into the plant from the soil and thus aiding in the drying process. A large amount of moisture remains in the back of the sunflower head after it is matured to the point where the seed will not be damaged by frost. Because of this moisture it is advisable to have the crop mature in the early fall when the weather is still warm and drying will be facilitated.

*Height of Plants, Seed Size and Percentage Kernel*

In addition to the data presented in Tables 1 and 2, measurements have been secured on height, seed size and percentage kernel. These results are presented in Table 3 for 1940, the only year when data were gathered for all three factors.

TABLE 3.—INFLUENCE OF DATE OF SEEDING ON HEIGHT OF PLANTS, WEIGHT PER 1,000 SEEDS AND PERCENTAGE OF KERNEL OF MENNONITE VARIETY, 1940

| Date of seeding | Height | Weight per 1,000 seeds | Percentage kernel |
|---|---|---|---|
| | in. | gm. | % |
| April 20 | 36.0 | 86.8 | 52.7 |
| May 1 | 37.8 | 85.8 | 52.1 |
| May 10 | 40.5 | 92.1 | 54.4 |
| May 20 | 42.7 | 89.3 | 53.7 |
| June 1 | 41.8 | 68.5 | 56.3 |
| June 10 | 40.2 | 62.5 | 54.8 |
| Necessary difference, 19 : 1 odds | 4.18 | 6.46 | 2.63 |
| Necessary difference, 99 : 1 odds | 5.79 | 8.93 | 3.64 |

The data for height show that the two earlier dates are significantly different from the May 20 date, which is the tallest. Little practical significance need be attached to these differences. It is true that in material to be combined the shorter heights of the earlier dates would be desirable but the difference is not enough to be of major consideration.

The two factors, weight per 1000 seeds and percentage kernel, show an inverse relationship which is in general agreement with earlier findings (1). The June dates both show smaller seed size and higher kernel content than the other dates. Both of these are desirable factors, the former because small seed would break up less in threshing than large seed and the latter because kernel content is closely associated with oil content (1). However, the much lower yield and later maturity of the June dates of seeding completely nullify any benefit from their smaller seed size and higher kernel content.

## PLANT SPACING TEST

*Seed Yield*

As explained under "materials and methods" this test was conducted for 3 years in a 4-replicate randomized block test with 6 spacings using the Mennonite variety. In the next 2 years a split plot design using 2 varieties with 3 spacings and 6 replicates was employed. The data for 4 replicates of the Mennonite variety from the last 2 years has been analyzed with the data from the test in the first 3 years, thus providing data on the Mennonite variety for 5 years at 3 spacings. A summary of the data for the seed yield of the Mennonite variety for 3 years with 6 spacings is shown in Table 4, and for 3 spacings and 5 years in Table 5, with that for the split plot test with 2 strains in Table 6. A variance analysis similar to that

shown in Table 1 was used for the data of Tables 4 and 5. The analysis for the split plot test is shown in Table 6. It is similar to that used for the data of all factors of this test considered in later tables.

TABLE 4.—INFLUENCE OF PLANT SPACING ON THE SEED YIELD* OF THE MENNONITE VARIETY, 1937-1939

| Plant spacings | 1937 | 1938 | 1939 | Average |
|---|---|---|---|---|
| | lb. | lb. | lb. | lb. |
| 6 inches | 324 | 751 | 923 | 666.0 |
| 12 inches | 231 | 824 | 932 | 662.3 |
| 18 inches | 157 | 775 | 718 | 550.0 |
| 24 inches | 163 | 740 | 913 | 605.3 |
| 30 inches | 186 | 720 | 822 | 576.0 |
| 36 inches | 132 | 726 | 815 | 557.7 |
| Average | 198.8 | 756.0 | 853.8 | |

* Yield in pounds per acre.

Necessary difference for spacings, 19 : 1 odds — 93.3 pounds
Necessary difference for years, 19 : 1 odds — 65.9 pounds
Necessary difference for years, 99 : 1 odds — 88.0 pounds

TABLE 5.—INFLUENCE OF PLANT SPACINGS ON THE SEED YIELD* OF THE MENNONITE VARIETY, 1937-1941

| Plant spacing | 1937 | 1938 | 1939 | 1940 | 1941 | Average |
|---|---|---|---|---|---|---|
| | lb. | lb. | lb. | lb. | lb. | lb. |
| 6 inches | 324 | 751 | 923† | 1,224 | 973 | 839.0 |
| 18 inches | 157 | 775 | 718 | 1,096 | 1,027 | 754.6 |
| 36 inches | 132 | 726 | 815 | 662 | 748 | 616.6 |
| Average | 204.3 | 750.7 | 818.7 | 994.0 | 916.0 | |

* Yield in pounds per acre.
† Yield of one plot calculated because mice destroyed seed before weighing.

Necessary difference for spacings, 19 : 1 odds = 97.0 pounds
Necessary difference for spacings, 99 : 1 odds = 130.7 pounds
Necessary difference for years, 19 : 1 odds = 125.2 pounds
Necessary difference for years, 99 : 1 odds = 168.7 pounds

Tables 4, 5 and 6 all show that the narrower spacings are superior in yielding ability to the wider spacings. The variance analysis for the data of Table 4 gave an $F$ value for spacings of 2.43 with the $F$ value at the 5% point being 2.42. Considering the average yields it is seen that the 6-inch and 12-inch spacings both differ from the 18-inch and 36-inch by significant amounts. In Table 5, the averages of the 6-inch and 18-inch spacings for the 5 years, both exceed the 36-inch by differences greater than required for 99 : 1 odds, while the difference between the 6-inch and 18-inch spacings itself approaches that required from 19 : 1 odds.

TABLE 6.—INFLUENCE OF PLANT SPACING ON THE SEED YIELD* OF MENNONITE AND S-490 MATERIAL, 1940-1941

| Plant spacing | Mennonite | | S-490 | | Average for spacing |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| | lb. | lb. | lb. | lb. | |
| 6 inches | 1,243 | 830 | 1,416 | 857 | 1,086.5 |
| 18 inches | 1,076 | 979 | 1,242 | 964 | 1,065.2 |
| 36 inches | 682 | 686 | 908 | 645 | 730.2 |
| Average for variety | 916.0 | | 1,004.4 | | |

Average for year 1940—1,094.5
Average for year 1941— 826.8

Variance analysis in 10's of pounds

| Source | *D.F.* | Sum Squares | Variance | *F.* |
|---|---|---|---|---|
| Years | 1 | 12,773 | 12,773.0 | 8.28† |
| Replicates | 5 | 4,807 | 961.4 | — |
| Replicates × Years | 5 | 6,694 | 1,338.8 | — |
| Varieties | 1 | 1,413 | 1,413.0 | — |
| Varieties × Years | 1 | 1,811 | 1,811.0 | .17 |
| Error (1) | 10 | 15,436 | 1,543.6 | 1 |
| Spacings | 2 | 19,192 | 9,596.0 | 21.0†† |
| Spacings × Years | 2 | 4,365 | 2,182.5 | 4.79† |
| Spacings × Varieties | 2 | 17 | 8.5 | — |
| Spac. × Var. × Years | 2 | 138 | 69.0 | — |
| Error (2) | 40 | 18,229 | 455.7 | |
| Total | 71 | 84,875 | | |

* Yield in pounds per acre.
† Exceeds 5% point.
†† Exceeds 1% point.

Necessary difference for spacings, 19 : 1 odds — 124.0 pounds
Necessary difference for spacings, 99 : 1 odds — 165.8 pounds

In Table 6 the 6-inch and 18-inch spacing compared with the 36-inch both give differences which are highly significant, however the difference between the 6-inch and 18-inch spacings is very small. Examining the data it is seen that the 6-inch spacing yielded higher than the 18-inch spacing in 1940, while the reverse is true for 1941, which accounts for the small difference in these 2 spacings in the average of the 2 years. When the 1940 data are analyzed separately the difference between the 6-inch and 18-inch spacing is found to be highly significant, while considering the 1941 data alone it is found the difference which is in the opposite direction is also large enough to approach significance. This condition is shown by the significant interaction of spacings × years in the variance analysis of Table 6. Another point of special interest is the negligible variance for the interaction of spacing × varieties indicating that the behaviour of the different genetic material is consistent for the 3 spacings in the 2 years of the test.

*Plant Height*

Data on plant height as well as for the characters head diameter, weight per 1000 seeds and percentage kernel have been collected for 1939 with the 6-spacing test of the Mennonite variety and for the 2 years of 3-spacing test with the 2 varieties. Since the data for 1939 shows the same tendencies as those collected in 1940 and 1941, for the sake of brevity, only the results for the latter 2 years are presented. The data for plant height are shown in Table 7.

TABLE 7.—INFLUENCE OF PLANT SPACING ON THE PLANT HEIGHT* OF MENNONITE AND S-490 MATERIAL, 1940-1941

| Plant spacing | Mennonite | | S-490 | | Average for spacings |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| | in. | in. | in. | in. | in. |
| 6 inches | 44.3 | 37.1 | 52.8 | 44.0 | 44.7 |
| 18 inches | 40.4 | 35.5 | 46.1 | 43.0 | 41.3 |
| 36 inches | 40.1 | 36.8 | 44.0 | 40.7 | 40.4 |
| Average for varieties* | 39.1 | | 45.1 | | |
| Average for years† | 1940—44.7 | | 1941—39.6 | | |

* Height in inches.
† Difference exceeds 99 : 1 odds.

Necessary difference for spacings, 19 : 1 odds = 2.2 inches
Necessary difference for spacings, 99 : 1 odds = 2.9 inches

Table 7 shows that the differences in height between the 2 varieties and between the 2 years are highly significant. The narrower spacings produce taller plants with the differences between the 6-inch spacing and both of the 2 wider spacings being highly significant, but the difference between the 2 wider spacings remaining insignificant. The variance analysis also showed no interaction of spacings × varieties, or of spacings × years, indicating that the effect of the different spacings was consistent for the different materials and for the years in which the test was made.

*Head Diameter*

The data for head diameter are presented in Table 8.

TABLE 8.—INFLUENCE OF PLANT SPACING ON THE HEAD DIAMETER* OF MENNONITE AND S-490 MATERIAL, 1940-1941

| Plant spacing | Mennonite | | S-490 | | Average for spacings |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| | in. | in | in. | in. | in. |
| 6 inches | 4.8 | 4.0 | 5.0 | 4.5 | 4.6 |
| 18 inches | 6.5 | 5.4 | 6.8 | 5.4 | 6.0 |
| 36 inches | 7.1 | 5.8 | 7.8 | 6.3 | 6.7 |
| Average for varieties | 5.9 | | 5.6 | | |
| Average for years† | 1940—6.33 | | 1941—5.2 | | |

* Diameter in inches.
† Difference exceeds 99 : 1 odds.

Necessary difference for spacings, 19 : 1 odds = .33 inches
Necessary difference for spacings, 99 : 1 odds = .45 inches

As would be expected these data show that the 6-inch plant spacing results in the smallest head diameter. It differs by high significance from both other spacings. The 2 wider spacings also differ from each other by high significance. As with plant height the variance analysis showed no significant interaction between varieties and spacings. The interaction between years and spacings, however, approached the significant level. In previous studies (1) there has been an indication that head diameter is positively associated with seed yield. Thus since there was a significant interaction of years × spacings in seed yield of Table 6, a similar interaction in the data for head diameter is not unexpected. The fact that the narrower spacings are higher yielding would seem to refute the finding that head diameter is positively associated with seed yield. However, it is seen that the head diameter does not decrease proportionately with the decrease in plant spacing; thus the larger number of heads in the smaller spacing would have a larger total seed bearing area and higher yields would be expected from them.

*Seed Size*

The data for seed size as measured by weight per 1000 seeds are presented in Table 9.

TABLE 9.—INFLUENCE OF PLANT SPACING ON WEIGHT PER 1,000 SEEDS OF MENNONITE AND S-490 MATERIAL, 1940-1941

| Plant spacing | Mennonite | | S-490 | | Average for spacings |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| | gm. | gm. | gm. | gm. | |
| 6 inches | 66.2 | 60.8 | 62.5 | 48.0 | 59.4 |
| 18 inches | 86.8 | 75.1 | 73.6 | 55.8 | 72.9 |
| 36 inches | 94.7 | 82.7 | 78.5 | 61.8 | 79.5 |
| Average for varieties* | 77.7 | | 63.5 | | |
| Average for years* | 1940—77.1 | | 1941—64.1 | | |

* Difference exceeds 99 : 1 odds.

Necessary difference for spacings, 19 : 1 odds = 3.51 grams
Necessary difference for spacings, 99 : 1 odds = 4.69 grams

From the data in Table 9 it is seen that the narrower spacings give smaller seed size. This is especially true of the 6-inch spacing which is 12.5 grams less than the 18-inch spacing and 20.1 grams less than the 36-inch spacing. All combinations of the 3 spacings give differences which exceed 99 : 1 odds of having occurred by chance alone. It is also seen that the difference between the varieties and between the years is highly significant. In addition the variance analysis showed a significant interaction between varieties and spacings. Examination of the data reveals that this is due to the more pronounced reduction of seed size which the narrower spacings brought about in the case of the larger seeded

Mennonite variety. For example in 1940 the difference between the 6-inch and 36-inch spacing in the Mennonite variety is 28.5 grams while in the S-490 material it is only 16 grams.

*Percentage Kernel*

Table 10 provides a summary of the data for percentage of kernel in the seed.

TABLE 10.—INFLUENCE OF PLANT SPACING ON THE PERCENTAGE KERNEL OF MENNONITE AND S-490 MATERIAL, 1940-1941

| Plant spacing | Mennonite | | S-490 | | Average for spacings |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| | % | % | % | % | |
| 6 inches | 57.8 | 57.0 | 62.0 | 55.5 | 58.0 |
| 18 inches | 54.7 | 55.2 | 61.8 | 55.5 | 56.7 |
| 36 inches | 53.3 | 54.8 | 61.4 | 54.5 | 55.9 |
| Average for varieties* | 55.3 | | 58.4 | | |
| Average for years* | 1940—58.5 | | 1941—55.3 | | |

* Difference exceeds 99 : 1 odds.

Necessary difference for spacings, 19 : 1 odds = 0.85%
Necessary difference for spacings, 99 : 1 odds = 1.14%

In agreement with the negative association between seed size and percentage kernel (1), the data for percentage kernel are in direct contrast to the data for seed size. The 6-inch spacing gives the highest percentage kernel, the difference between it and the two wider spacings being highly significant in both cases. Similarly the 18-inch spacing shows a higher kernel content than the 36-inch spacing. The difference in this case, however, only approaches significance. The differences between the 2 varieties and the 2 years are also highly significant but again the relationship shown is in contrast to the seed size data. As with the seed size the variance analysis showed a significant interaction between varieties and spacings due again to the greater effect of spacings on the larger seeded Mennonite variety. Considering the 1940 data, for example, it is seen that the difference between the 2 extreme spacings is 4.5% for the Mennonite variety and only 0.6% for the S-490 material. Another significant interaction, not shown by variance analysis of the data for other factors, is between varieties and years. This is mainly due to the low percentage kernel of the S-490 material in 1940 as compared with 1941.

*Oil Content of Seed*

Because of the time and expense involved in oil analyses, data were not secured for each plot in the test. Instead the plots were bulked according to spacings and varieties and an analysis secured on these bulk samples only. Table 11 presents the results for 3 years and 3 spacings with the Mennonite variety and Table 12 those for 1940 and 1941 from the test with 2 varieties.

TABLE 11.—INFLUENCE OF PLANT SPACINGS ON THE PERCENTAGE OIL IN THE WHOLE SEED OF MENNONITE VARIETY, 1939-1941

(Dry weight basis)

| Plant spacing | 1939 | 1940 | 1941 | Average |
|---|---|---|---|---|
| | % | % | % | |
| 6 inches | 29.9 | 27.0 | 31.2 | 29.4 |
| 18 inches | 28.0 | 24.5 | 28.3 | 26.9 |
| 36 inches | 24.2 | 23.8 | 27.0 | 25.0 |
| Average for years | 27.4 | 25.1 | 28.8 | |

Necessary difference for spacings and years, 19 : 1 odds — 1.97%
Necessary difference for spacings, 99 : 1 odds — 3.27%

TABLE 12.—INFLUENCE OF PLANT SPACING ON THE PERCENTAGE OIL IN THE WHOLE SEED OF MENNONITE AND S-490 MATERIAL, 1940-1941

(Dry weight basis)

| Plant spacing | Mennonite | | S-490 | | Average for spacings |
|---|---|---|---|---|---|
| | 1940 | 1941 | 1940 | 1941 | |
| 6 inches | 27.0 | 31.2 | 33.7 | 32.1 | 31.0 |
| 18 inches | 24.5 | 28.3 | 33.4 | 29.7 | 29.0 |
| 36 inches | 23.8 | 27.0 | 32.1 | 30.6 | 28.4 |
| Average for varieties* | 27.0 | | 31.9 | | |
| Average for years | 1940—29.1 | | 1941—29.8 | | |

* Difference exceeds 99 : 1 odds.

Necessary difference for spacings, 19 : 1 odds = 1.80%

The data of Tables 11 and 12 show clearly that the narrower spacings yield seed with higher oil content. In both sets of data the differences between the 6-inch spacing and the other 2 spacings exceed odds of 19 : 1 of having occurred by chance and in Table 11 the difference between the 6-inch and 36-inch spacings exceeds odds of 99 : 1. In Table 12 the difference between the 2 varieties is highly significant, indicating the desirability of the S-490 material from the standpoint of oil production.

In Table 11 the difference between the 1940 year and the other 2 years are significant. Other differences between years are not significant. However there is a significant interaction for varieties × years shown by the variance analysis of the data in Table 12. This is due to the higher oil content of the Mennonite material in 1941 as compared with 1940 and the lower oil content of the S-490 material in 1941 as compared with 1940.

## DATE OF HARVEST TEST

### *Seed Yield*

One of the chief objectives of the date of harvest test was to determine if any serious seed losses occurred when the plants were allowed to stand until well dried after they had become mature. A summary of the seed yields for this test over the 3-year period, 1939-1941, is shown in Table 13.

TABLE 13.—SUMMARY OF SEED YIELDS* FOR DATE OF HARVEST TEST, 1939-1941

| Date of harvest | 1939 | 1940 | 1941 | Average |
|---|---|---|---|---|
| | lb. | lb. | lb. | lb. |
| September 1 | 824 | 973 | 890 | 895.7 |
| September 10 | 1,022 | 795 | 872 | 896.3 |
| September 20 | 930 | 835 | 1,010 | 925.0 |
| October 1 | 993 | 789 | 817 | 866.3 |
| October 10 | 1,008 | 829 | 1,012 | 949.7 |
| October 20 | 920 | 896 | 854 | 890.0 |
| Average for years | 949.5 | 852.8 | 909.2 | |

* Yield in pounds per acre.

Necessary difference for years, 19 : 1 odds — 74.0 pounds

The results of Table 13 show that there is no loss of yield as a result of letting the plants stand in the field after maturity. Variance analysis does not reveal any significant differences between the various dates of harvest. It is also worthy of note that the two latest dates do not show the lowest yield either on the average of the 3 years or in any single year.

The variance analysis does show that significant differences exist between the years in all comparisons.

*Moisture Losses and Condition after Storage*

In Table 14 the amounts of moisture lost between harvesting and the point where the seed reached air dry weight are shown. These data were collected after the seed had first been stored to determine the amount of spoiling which would occur with the moisture that was present at harvest time.

TABLE 14.—SUMMARY OF MOISTURE LOSS IN PER CENT AT AIR DRY WEIGHT FOR SEED HARVESTED AT DIFFERENT DATES. (BASED ON WEIGHT AT HARVEST)

| Date of harvest | 1939 | 1940 | 1941 |
|---|---|---|---|
| | % | % | % |
| September 1 | 34.7 | 29.7 | 42.8 |
| September 10 | 18.8 | 19.6 | 28.1 |
| September 20 | 6.4* | 8.3* | 13.6 |
| October 1 | | 7.3 | 6.6* |
| October 10 | | 4.7 | 8.5 |
| October 20 | | 4.0 | 1.7 |

* Date at which and after which no spoilage was observed for the year indicated.

Table 14 shows that spoiling occurred in all the samples which were harvested on the first 2 dates. Usually the spoilage was severe, especially in the first date when the whole mass of material was salmon coloured due to the fungal growth which developed during storage. There was also a strong smell of ammonia from these samples which would indicate that protein decomposition had occurred. With the high moisture loss shown by the samples harvested on the first 2 dates spoilage would be expected. With the third date spoiling occurred only in 1941.

In considering what is the upper moisture limit for safe storage of sunflower seed, Table 14 indicates that it is between 8.5% and 13.6% of free moisture. One of the samples for the third date for 1940 which was safely stored contained 9.2% free moisture while a sample from the third date containing 13.2% free moisture was spoiled in storage.

In July 1942 the moisture content of 2 of the air dry samples from each date of the 1941 test was determined. The range in these determinations was from 4.9% to 6.4% with an average for the 12 samples of 5.8%. Using this figure in conjunction with the data of Table 14, in calculating, the samples from the third and fifth dates, in 1941, are found to have contained 81.4% and 86.2% of dry matter, respectively at harvest. This indicates that the upper limit of absolute moisture content for safe storage of sunflower seed is between 18.6% and 13.8%.

The determinations of the moisture content of the air dry samples were made following a long period of high relative humidity. After such weather they would likely contain more moisture than they did when the data for Table 14 were secured, following air drying in the fall of 1941. With this in mind, it is felt that 5.8% is probably a high estimate of the moisture content of the air dried samples. Other material stored under the same conditions which was forwarded to the Grain Research Laboratory, Winnipeg, for oil content determination contained only about 4% of moisture. Thus it is felt the limit of absolute moisture content for safe storage is likely closer to 13.8% than to 18.6% and may be below 13.8%.

*Oil Content and Other Seed Factors*

Determination of percentage kernel and weight per 1000 seeds as well as oil content have been secured. To conserve space, only the results of the oil content determinations are presented. These are shown in Table 15.

It is of interest to note that significant differences occurred between the different dates for both percentage kernel and weight per 1000 seeds. These differences were caused in both cases mainly by low figures for the first date of harvest. Probably these low figures were due to two factors; first, the crop was a few days from being mature at the first harvest date and second, very severe spoilage occurred in this slightly immature seed.

Variance analysis of the data contained in Table 15 indicate that there are no significant differences in oil content of seed from the different dates

TABLE 15.—PERCENTAGE OIL IN SEED HARVESTED AT DIFFERENT DATES

| Date of harvest | 1939 | 1940 | 1941 | Average |
|---|---|---|---|---|
| | % | % | % | % |
| September 1 | 25.8 | 26.3 | 27.9 | 26.7 |
| September 10 | 24.7 | 24.5 | 29.0 | 26.1 |
| September 20 | 25.6 | 26.8 | 28.4 | 26.9 |
| October 1 | 26.9 | 24.7 | 28.3 | 26.6 |
| October 10 | 28.3 | 24.9 | 28.1 | 27.1 |
| October 20 | 25.1 | 26.1 | 28.5 | 26.8 |
| Average for years | 26.1 | 25.6 | 28.4 | |

Necessary difference for years, odds 19 : 1 = 1.42%
Necessary difference for years, odds 99 : 1 = 2.02%

of harvest, which shows that allowing the crop to stand in the field for a long period after maturity does not affect the oil content of the seed sample.

It is surprising that the material harvested on the first date does not have a lower oil content than that from the later dates. It has been mentioned above that this material was harvested a few days before it was mature and that it spoiled severely in storage but apparently without affecting the oil content. However, the possibility still remains that the quality of the oil might not be the same in the immature and spoiled samples as in well matured and dried samples secured from the late dates of harvest.

## DISCUSSION AND CONCLUSIONS

The results presented in this paper from the date of seeding studies show that the seeding on May 20 gives higher seed yields than later or earlier dates of seeding. However, as has been mentioned, seeding in early May with the sacrifice of some yield might be advisable in order to ensure maturity in the early part of the fall, and thus secure warmer weather for drying the back of the head sufficiently for combining. This would apply especially to any areas with shorter growing seasons than at Saskatoon.

It should also be mentioned that the results presented here are for the Mennonite variety only. It is likely that another variety or strain, particularly one of earlier or later maturity than the Mennonite material, would respond in a different way to the various seeding dates.

The results from the plant spacing test definitely favour the narrower spacing in the row. This test has shown that a higher yield of seed with a higher percentage of oil in the seed is secured from the narrower spacing. The two factors, higher yield and high oil content are two major considerations in production of sunflower seed as an oil source. However, the narrower spacing is also desirable in other respects. As has been shown, it produces smaller seed which is probably mainly responsible for the higher kernel and oil content, but this smaller seed is desirable in itself, because it will likely break up less than large seed in threshing.

With respect to other plant characters, the narrower spacing has desirable features. It suppresses branching tendencies in the material, thus ensuring more uniform maturity than the wide spacing. It also provides a plant with a smaller head. While no data to substantiate the belief have been collected, it is felt such heads would dry out faster and be ready for harvesting with the combine before those in the wider spacing. It is also conceivable that the smaller heads would cause less wear and tear on the harvesting machinery than large heads. In the matter of plant height the smaller spacing is not desirable because the increased height gives increased stem for the decks to carry in threshing. However, this factor is out-weighed by the other desirable features of the narrow spacing.

In one other respect the narrower spacing is desirable. It can be seeded successfully with the ordinary grain drill, which means that no new equipment will be needed by the Western Canadian farmers for sowing the crop. While it is not possible to secure an accurate 6-inch spacing by using a grain drill, it can be set to drop the seeds so that the resulting stand will closely approach the desired spacing. Stands of desirable plant spacing have been obtained in 1941 and 1942 with the ordinary grain drill at Saskatoon.

The date of harvest test does not reveal any particular date as suitable for harvest. It does show that the heads contain a large amount of moisture after the plants are mature and that the time of harvesting will depend on the time required for this moisture to dry out, which in turn is dependent on weather conditions. The results which have been presented in this paper indicate that a period of 3 to 4 weeks after maturing is required for reducing the moisture content of the seed to levels which will be safe for storage. The results further show that there is no loss in seed yield or oil content in allowing the plants to stand after maturity so that this period could be extended to several weeks without affecting the value of the crop, and at the same time providing greater assurance of safe moisture levels for storage being reached.

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## SUMMARY

1. The results of tests studying the influence of date of seeding, date of harvest, and plant spacing within the row are presented.

2. The May 20 date of seeding gave higher yields of seed than earlier or later dates as an average of 3 years results with the Mennonite variety. Seedings earlier than this date gave yields greater than the later seedings suggesting that the seeding date, at least for Mennonite material should be on or before May 20.

3. The study of plant spacing within the row showed that the 6-inch spacing was more desirable than wider spacings. It gave a higher yield of seed with higher kernel content, lower weight per 1000 seeds and higher oil content than wider spacings. The plants of the narrower spacing while taller, showed less branching and bore smaller heads than those in the wider spacings.

4. The date of harvest test shows the plants must stand 3 to 4 weeks after maturity before the seed reaches a moisture content low enough for safe storage. No loss in seed yield or oil content is caused by this delay after maturing. The date of maturity is considered as that stage when the heads are yellow in the back with the involucral bracts turning brown.

5. Indications from the date of harvest test are that the upper limit of absolute moisture content for safe storage of seed is between 13.8 and 18.6%, with the figure probably being closer to 13.8 than 18.6. The upper limit of free moisture content for safe storage is between 8.5 and 13.6%.

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# THE WINTER SURVIVAL OF GRASS AND LEGUME PLANTS IN FALL SOWN PLOTS[1]

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As crested wheat grass became distributed in Western Canada and experimental studies with this crop expanded, it was found that this grass could be sown in the fall with success. The trend to fall seeding increased until at present a considerable proportion of the total acreage sown each year to this grass is planted at this season of the year. Experience in the drier parts of Western Canada has shown that fall seeding often offers greater chance of successful establishment of the crop than does even the earliest spring seeding (1, 3).

While investigators generally agree on the success of fall seeding their opinions differ as to the most suitable time in the fall to seed. Kirk *et al.* (2) in 1937 considered that seeding during the first half of September gave best results. Stevenson *et al.* (4) in 1939 recommended seeding in early September if moisture conditions were good or in late October or early November. They warned that warm periods following late fall seeding might initiate germination and the resulting seedlings might be injured by low temperatures. However, in large scale seeding on community pastures in the Prairie Provinces the common practice has been to commence seeding in early fall and continue till freeze-up.

In order to secure more detailed information on the best time to fall seed a study was commenced in the fall of 1937 in which plants of varying sizes were marked at freeze-up and their survival recorded. Because the success with fall seeding of crested wheat grass had aroused interest in the possibility of fall seeding of other grasses and legumes, brome grass, slender wheat grass, alfalfa and sweet clover were also included in the study. This paper summarizes the results obtained to date.

## MATERIAL AND METHODS

The plots in the dates of seeding tests were at first utilized in this study. These plots were sown on summerfallow on the first and fifteenth of each month from early spring until freeze-up, those sown from September 1 onward were used in this study. The rather heavy rates of seeding and emergence in these plots made positive identification of seedlings difficult at times. Consequently in later years, space-planted seedings were made at intervals in the fall. The space-planted plots were located on both summerfallow and in stubble. One series was sown on summerfallow in 1939 and covered with canvas tents from which the snow was removed periodically in an attempt to produce more severe winter conditions. The results were comparable to plots on stubble and the data have been included along with that from stubble plots. To ensure immediate and satisfactory

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germination the space-planted plots were watered on some occasions immediately after seeding. Large plots sown on weedy abandoned land in the vicinity of Saskatoon were used also for the study.

In determining winter survival the method used was to mark each individual plant with a wire peg placed well in the ground as close to it as possible. In the case of unemerged seedlings the soil was carefully removed to locate the plants and then replaced after marking. In the period October 18 to 25 (usually 7 to 10 days prior to freeze-up) a record was made of the stage of development of each individual plant. Early in May the following year the records were completed by taking notes on winter survival. For purposes of summarizing the data, the fall stages of development were grouped into 6 classes in the case of the grasses and 5 in the legumes.

During the early spring of at least 2 years some soil drifting occurred among summerfallow plots utilized for this study. This may have resulted in some mortality, particularly of younger plants, that could not be distinguished from winter killing. However, as will be shown later, the very comparable results from summerfallow in years when drifting was not encountered and from plots on stubble (as will be shown later), is evidence that soil erosion was not a serious disturbing factor and consequently that the killing was largely the effect of failure to survive the winter.

On studying the influence of temperature on germination the Laboratory of the Plant Products Division, Production Service, Saskatoon, kindly conducted the tests. Their equipment permitted a temperature control of $\pm$ 1° C. In all tests conducted at low temperatures the germination sample consisted of a total of 200 seeds and in most of the checks at normal germination temperatures this size of sample was used. Otherwise, germination was determined on 100 seeds.

## RESULTS

### WINTER SURVIVAL

The data on comparative winter survival of plants of the 3 species of grass when grown on summerfallow for the 5-year period, 1937-38 to 1941-42, are given in Table 1. Examination of the data reveals that there is a positive association between stage of development at freeze-up and winter survival. Plants which had not emerged or had just emerged 7 to 10 days prior to freeze-up had a low winter survival, while those which had reached the 3-leaf or a more advanced stage had a high winter survival. Plants intermediate between these extremes of plant development had intermediate degrees of survival.

It is shown also in Table 1 that the survival of all three grass species was very similar. Brome grass appears to have killed to a greater extent than crested wheat grass but this is considered to be due to chance variations rather than any real difference.

TABLE 1.—THE RELATION BETWEEN STAGE OF DEVELOPMENT AND WINTER SURVIVAL OF PLANTS OF THREE SPECIES OF GRASS GROWN ON SUMMERFALLOW, 1937-38 TO 1941-42

| Stage of growth in fall | Crested wheat | | Brome | | Slender wheat* | | All grasses | |
|---|---|---|---|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % | | % | | % |
| Unemerged | 118 | 27.1 | 99 | 18.2 | 173 | 13.3 | 390 | 18.7 |
| 1 leaf up to ½" | 136 | 30.9 | 114 | 7.9 | 60 | 31.7 | 310 | 22.6 |
| 1 leaf over ½" | 173 | 61.3 | 215 | 43.3 | 54 | 44.4 | 442 | 50.4 |
| 2 leaves up to 2" | 91 | 78.0 | 109 | 88.1 | 107 | 64.5 | 307 | 76.9 |
| 2 leaves over 2" | 14 | 78.6 | 25 | 52.0 | 22 | 81.8 | 61 | 68.8 |
| 3 or more leaves | 181 | 98.9 | 128 | 82.8 | 90 | 96.7 | 399 | 93.2 |

* 1937-38 to 1940-41 only.

Alfalfa was found to react very differently from sweet clover when fall sown, as is shown in Table 2. Alfalfa plants beyond the cotyledon stage survived fairly well, while sweet clover plants killed almost completely irrespective of stage of development. In only 1 year (1941-42) were a few sweet clover plants found which over wintered. This marked difference between the two legumes was often evident at the time the late fall records were being taken. Alfalfa plants rarely showed frost injury at that time while sweet clover plants usually exhibited severe damage. In fact, it is considered that a fairly large portion of the sweet clover plants were killed by frosts prior to freeze-up.

The survival of alfalfa is considerably lower than that of the grasses for comparable times of seeding. However, the relationship noted in the grasses between stage of development at freeze-up and survival is also evident in the case of alfalfa although to a less marked degree.

TABLE 2.—THE RELATION BETWEEN STAGE OF DEVELOPMENT AND WINTER SURVIVAL OF LEGUME PLANTS GROWN ON SUMMERFALLOW, 1938-39 TO 1941-42

| Stage of growth in fall | Alfalfa | | Sweet clover | |
|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % |
| Unemerged | 25 | 0.0 | 10 | 0.0 |
| Cotyledons only | 141 | 11.3 | 219 | 0.0 |
| 1 leaf | 201 | 34.8 | 101 | 0.0 |
| 2 leaves | 49 | 18.7 | 87 | 0.0 |
| 3 or more leaves | 114 | 48.2 | 115 | 15.4 |

Evidence of severe killing of crested wheat grass fall sown on summerfallow was obtained from a farmer at Landis, Sask. The field was sown in rows 36 inches apart in early September, 1938, and the germination occurred over a considerable period so that by freeze-up the plants varied in size from just emerged to about 2 inches high. The winter snowfall was light

and the farmer reported that no soil drifting occurred the next spring. A soil sample including the plants was taken on May 5, 1939. Of the 37 plants contained in the samples only 8, or 21.5% were alive.

As is shown in Table 3, the grasses when grown on stubble or dead weeds displayed the same relationship as were noted above for summerfallow plots. The winter survival was very closely associated with stage of development at freeze-up, and the survival of all three grasses was very similar.

TABLE 3.—THE RELATION BETWEEN STAGE OF DEVELOPMENT AND WINTER SURVIVAL OF PLANTS OF THREE GRASSES GROWN IN STUBBLE AND WEEDS (1937-38 TO 1940-41)

| Stage of growth in fall | Crested wheat | | Brome | | Slender wheat* | | All grasses | |
|---|---|---|---|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % | | % | | % |
| Unemerged | 53 | 47.2 | 103 | 57.3 | 77 | 44.2 | 223 | 50.6 |
| 1 leaf up to ½" | 50 | 58.0 | 195 | 65.6 | 72 | 72.2 | 317 | 65.9 |
| 1 leaf over ½" | 222 | 82.9 | 64 | 54.7 | 51 | 80.4 | 337 | 77.2 |
| 2 leaves up to 2" | 67 | 92.5 | 58 | 77.6 | 69 | 81.2 | 194 | 84.0 |
| 2 leaves over 2" | 45 | 97.8 | 18 | 94.4 | 12 | 91.7 | 75 | 96.0 |
| 3 or more leaves | 27 | 100.0 | 3 | 100.0 | 1 | 100.0 | 31 | 100.0 |

* 1937-38 to 1939-40 only.

When sown on stubble or weeds the legumes also reacted in a manner similar to that on summerfallow as is shown in Table 4. Sweet clover plants winter killed completely while alfalfa survived fairly well, the survival being related to stage of development at freeze-up.

TABLE 4.—THE RELATION BETWEEN STAGE OF DEVELOPMENT AND WINTER SURVIVAL OF LEGUME PLANTS GROWN IN STUBBLE AND WEEDS (1938-39 TO 1939-40)

| Stage of growth in fall | Alfalfa | | Sweet clover | |
|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % |
| Unemerged | — | — | — | — |
| Cotyledons only | 133 | 21.1 | 132 | 0.0 |
| 1 leaf | 106 | 60.4 | 84 | 0.0 |
| 2 leaves | 21 | 81.0 | — | — |
| 3 or more leaves | — | — | — | — |

Observations in May 1939 on a 10-acre field of crested wheat grass sown into stubble on September 28, 1938, indicated that killing was at least as severe as in the small plots used in this study. Six samples taken at random over the 10-acre field contained 121 plants of which only 36, or 28.1% were living.

Examination of the data in Tables 1 and 3, and 2 and 4, reveals a considerable difference between survival on summerfallow and in stubble. To facilitate the comparison the data for the two sets of conditions are summarized in Table 5.

TABLE 5.—RELATIVE WINTER SURVIVAL OF GRASS AND LEGUME PLANTS GROWN ON SUMMERFALLOW AND IN STUBBLE AND WEEDS

| Stage of growth in fall* | Crested wheat | | Brome | | Slender wheat | | All grasses | | Alfalfa | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage survival on | | Percentage survival on | | Percentage survival on | | Percentage survival on | | Percentage survival on | |
| | Fallow | Stubble | Fallow | Stubble | Fallow | Stubble | Fallow | Stubble | Fallow | Stubble |
| | % | % | % | % | % | % | % | % | % | % |
| Unemerged | 27.1 | 47.2 | 18.2 | 57.3 | 13.3 | 44.2 | 18.7 | 50.6 | 0.0 | — |
| 1 leaf up to ½" | 30.9 | 58.0 | 7.9 | 65.6 | 31.7 | 72.2 | 22.6 | 65.9 | 11.3 | 21.1 |
| 1 leaf over ½" | 61.3 | 82.9 | 43.3 | 54.7 | 44.4 | 80.4 | 50.4 | 77.2 | 34.8 | 60.4 |
| 2 leaves up to 2" | 78.0 | 92.5 | 88.1 | 77.6 | 64.5 | 81.2 | 76.9 | 84.0 | 18.7 | 81.0 |
| 2 leaves over 2" | 78.6 | 97.8 | 52.0 | 94.4 | 81.8 | 91.7 | 68.8 | 96.0 | 48.2 | — |
| 3 or more leaves | 98.9 | 100.0 | 82.8 | 100.0 | 96.7 | 100.0 | 93.2 | 100.0 | — | — |

* Given for grasses, alfalfa comparable.

From Table 5 it is clearly evident that the survival in stubble and weeds was considerably higher than on summerfallow. The difference is particularly great in plants in the younger stages of development. The higher survival in stubble and weeds is considered to be due to the greater protection afforded by the snow.

Further evidence of the influence of depth of snow cover in winter survival was obtained in a paddock about 3 acres in size which was plowed up and seeded to a mixture of crested wheat, brome, slender wheat and

FIGURE 1. The influence of snow cover on winter survival. Left—Grasses and alfalfa killed out in foreground but living in background where snow accumulated to north of snow fence (white line indicates position of snow fence). Right—Grasses and alfalfa living in dead furrow but killed on higher land and each side of furrow.

alfalfa on August 17, 1938. Good rains in the early part of September resulted in a heavy growth by freeze-up. The paddock was so situated that some ashes and cinders from the University power-house were blown out onto it. This resulted in earlier than usual melting of the snow. Considerable snow accumulated on the north side of a snow fence running east and west through the paddock. The following spring it was found that the plants of all four species were killed out almost completely on all the high land in the paddock, but had lived on the lower lying land which presumably had a deeper snow covering. The plants had also survived well on each side of the snow fence and also in a dead furrow. Obviously this was due to the greater snow depth in these locations. The effect is illustrated in Figure 1.

The data as presented above have given the survival of plants over a period of years. It is of importance to know what variation may occur from year to year. The data by years for the grasses grown on summerfallow and stubble are presented in Tables 6 and 7, respectively. Since it has been shown previously that all 3 grasses behave similarly with respect to survival the data for the 3 species for each year have been combined in these tables.

TABLE 6.—WINTER SURVIVAL BY YEARS OF PLANTS OF THREE GRASSES GROWN ON SUMMERFALLOW

| Stage of growth | 1937-38 | | 1938-39 | | 1939-40 | | 1940-41 | | 1941-42 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % | | % | | % | | % |
| Unemerged | 114 | 43.8 | 158 | 0.6 | 42 | 2.4 | 76 | 27.6 | — | — |
| 1 leaf up to ½" | 23 | 30.4 | 82 | 23.2 | 56 | 5.4 | 27 | 33.3 | 122 | 26.2 |
| 1 leaf over ½" | 4 | 75.0 | 30 | 40.0 | 48 | 12.5 | 257 | 64.2 | 103 | 35.9 |
| 2 leaves up to 2" | 20 | 85.0 | 17 | 76.5 | 37 | 29.7 | 193 | 83.9 | 40 | 82.5 |
| 2 leaves over 2" | 10 | 90.0 | 14 | 57.1 | 31 | 64.5 | 6 | 83.3 | — | — |
| 3 or more leaves | 32 | 84.4 | 227 | 95.6 | 68 | 82.4 | 36 | 100.0 | 36 | 100.0 |
| Weighted average | — | 68.1 | — | 48.8 | — | 32.8 | — | 65.4 | — | 60.2 |

TABLE 7.—WINTER SURVIVAL BY YEARS OF PLANTS OF THREE GRASSES GROWN ON STUBBLE

| Stage of growth | 1937-38 | | 1938-39 | | 1939-40 | | 1940-41 | |
|---|---|---|---|---|---|---|---|---|
| | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival | No. of plants | Percentage survival |
| | | % | | % | | % | | % |
| Unemerged | 38 | 65.8 | — | — | 89 | 38.2 | 106 | 55.7 |
| 1 leaf up to ½" | 93 | 87.1 | 43 | 74.4 | 148 | 47.3 | 33 | 78.8 |
| 1 leaf over ½" | 89 | 96.6 | 81 | 86.4 | 118 | 59.3 | 49 | 69.4 |
| 2 leaves up to 2" | — | — | 29 | 93.1 | 153 | 81.0 | 12 | 100.0 |
| 2 leaves over 2" | — | — | 15 | 93.3 | 59 | 96.6 | 1 | 100.0 |
| 3 or more leaves | — | — | 2 | 100.0 | 28 | 100.0 | 1 | 100.0 |
| Weighted average | — | 83.2 | — | 89.4 | — | 70.4 | — | 84.0 |

As might be expected, Tables 6 and 7 reveal that the survival is higher in some winters than others. This is particularly observable in material grown on summerfallow, as shown in Table 6. The winter of 1938-39 and 1939-40 resulted in considerably lower survival than other winters.

Although Tables 6 and 7 show that survival varies with the winter they also very clearly reveal the same relationship between size of plant and survival as has been shown in previous tables. It is obvious that the smaller the plant the more influence the severity of the winter exerts. Thus the survival of plants having 3 or more leaves was high more or less irrespective of the severity of the winter.

## EFFECT OF TEMPERATURE ON GERMINATION

Throughout the study it was observed that in seedings made October 1 and 15, if moisture conditions were satisfactory, small plants and unemerged seedlings were relatively abundant in plots of crested wheat grass, alfalfa, and sweet clover, and comparatively scarce in plots of brome and slender wheat grass. This phenomenon appeared to be a differential response of species to low germination temperatures. In checking the matter further, the Laboratory of the Plant Products Division, Production Service, Saskatoon, kindly conducted germination tests, the results from which are presented in Table 8.

TABLE 8.—INFLUENCE OF TEMPERATURE ON THE GERMINATION OF THREE GRASSES AND TWO LEGUME SPECIES

| Crop | Sample No. | Percentage germination at end of indicated number of days (in brackets) when held at the following temperatures | | | |
|---|---|---|---|---|---|
| | | 20-30° C. | 8° C. (6) 20-30° C. (8-10) | 8° C. | 5° C. |
| Brome grass | 1 | 84 (14) | 85 (16) | 17 (35) | 37 (35) |
| | 2 | — | 93 (14) | 36 (31) | — |
| Slender wheat | 1 | 53 (14) | 95 (16) | 0 (35) | 0 (35) |
| | 2 | — | 95 (14) | 7 (31) | — |
| Crested wheat | 1 | — | 88 (16) | 88 (35) | 88 (35) |
| | 2 | — | 96 (14) | 94 (31) | — |
| Alfalfa* | 1 | 40 (5)† | — | 55 (17) | 51 (24) |
| Sweet clover* | 1 | 84 (5)† | — | 82 (32) | — |
| | 2 | 88 (5)† | — | 93 (32) | — |
| | 3 | 48 (5)† | — | 50 (32) | — |

* Germination exclusive of hard seeds.
† At temperature of 18-20° C.

It is clearly evident from Table 8 that the ultimate germination of brome grass seed and particularly slender wheat grass seed was very greatly reduced while that of crested wheat and both legumes was not influenced when the temperature for germination was low. In all cases a considerably longer period was required for germination at the low temperature than at the accepted standard temperatures. These data lend strong

support to the theory arrived at from fall observations—namely, that late September and early October seedlings of brome and slender wheat grass fail to germinate satisfactorily because of the low soil temperatures.

If moisture conditions are favourable, a high percentage of germination follows the seeding of crested wheat grass, alfalfa, and sweet clover in the period from late September to mid October, and by freeze-up a development varying from unemerged seedlings to small plants is reached. From the data presented in Tables 1 to 7 the influence of the winter conditions on the survival of plants in these stages of development is known. But when brome grass or slender wheat grass are seeded at the above period of the year under favourable moisture conditions, only a relatively small percentage of the seeds germinate, but the ungerminated seeds are softened and swollen by the absorption of water. Very little information is available on the influence of winter temperatures on the ultimate germination of seeds in this condition. The small amount of data obtained from seeds washed from the soil indicated that over 75% of such seeds germinate in the spring.

## DISCUSSION AND CONCLUSIONS

In view of the relationship shown between stage of plant development at freeze-up and winter survival it is apparent that fall seeding should be done early enought to permit the plants to attain at least the 2-leaf stage and preferably the 3-leaf stage, before freeze-up, or otherwise seeding should be delayed to just prior to freeze-up. At Saskatoon the early fall seeding must be done before mid-September in order to permit the plants to reach the desired stage. Dates of seeding trials have shown that seeding prior to late August cannot be depended upon to give as satisfactory results as early September seeding. From a practical standpoint the choice of seeding in the period late August to mid-September or delaying until freeze-up depends on moisture conditions in the early period. If good rains are received in early September, seeding should be done immediately. Otherwise it should be delayed till just prior to freeze-up. Seeding into dry soil in early September is not advisable because the seed will not germinate until rain is received. Such rain may be just sufficient to germinate the seed and the plants succumb to drought later. On the other hand, heavy rains may occur so late that a large percentage of the plants will winter kill because they were not sufficiently developed.

In large scale seeding, such as in community pastures, it is, of course, not practical to adopt the above recommendations. However, the fact that in the past few years a large acreage has been successfully seeded in community pastures by commencing seeding in early fall and seeding continuously until freeze-up, does not invalidate the above stated conclusion respecting the most desirable periods for fall seeding.

While for the purpose of making recommendations regarding the fall seeding of crops other than crested wheat, the populations used in this study are undesirably small, certain conclusions may be drawn. Of the legumes it has been shown that sweet clover can definitely not be successfully established by seeding in the interval from September 1 to just about freeze-up. Seeding just prior to freeze-up is also considered to be risky due to the fact that germination will occur at low temperatures and that

the seedlings and young plants are fairly susceptible to frost damage. On the other hand, the data presented suggest that there is good prospects of being able to seed alfalfa either in the early fall or just before freeze-up. The winter survival of seedings made into stubble or weed covering ground September 1 was very satisfactory and the high frost resistance of the young plants indicates that there is likely to be very little damage from frosts in the spring following late fall seeding. Fall seeding of this crop is a recommended practice in Nebraska (15) and the results reported here would warrant fuller investigation of the possibility in Western Canada.

The similarity in winter survival of brome grass, slender wheat grass and crested wheat grass would indicate that the former two grasses could be fall sown. In view of the germination response of slender wheat and brome grass to low temperatures and the lack of knowledge of the effect of winter conditions on swollen but ungerminated seeds of these crops, it would seem highly desirable at the present time to recommend that they only be sown in the early fall (around September 1) or just prior to freeze-up.

## SUMMARY

1. Over the period 1937-38 to 1941-42 on plots sown at intervals from September 1 to freeze-up, the winter survival of plants of crested wheat gass, brome grass, slender wheat grass, alfalfa and sweet clover in various stages of development at freeze-up was studied.

2. When sown on summerfallow the percentage survival of plants of the 3 grasses was positively associated with stage of development at freeze-up, being 18.7% for unermerged seedlings and 93.2% for plants with 3 or more leaves. The survival of the 3 grasses was very similar.

3. The survival of alfalfa on summerfallow was lower than that of the grasses but displayed the same relationship to stage of development. That of sweet clover was almost nil irrespective of developmental stage.

4. The survival of grasses sown in stubble and weeds was considerably higher than on summerfallow. The difference between these 2 land conditions was particularly great in plants in the younger stages of development. As in summerfallow the behaviour of the 3 grasses was similar.

5. Alfalfa sown in stubble survived very well when in the more advanced stages of development, while sweet clover killed out completely irrespective of stage of development.

6. While the average survival varied from year to year the severity of the winter had little effect on the survival of plants in the more advanced stages of development.

7. Crested wheat grass, alfalfa, and sweet clover were shown to germinate well although slowly at temperatures of 5° C. and 8° C. while the germination of brome grass and slender wheat grass was poor at these temperatures.

8. It is recommended that fall seeding of the grasses and possibly alfalfa be done in the period from late August to mid-September if moisture conditions are good or just before freeze-up. Sweet clover should not be fall sown.

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# HERBICIDAL ACTION OF CHEMICALS ON PERENNIAL WEEDS[1]

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Perennial weeds are highly objectionable in cultivated soils due mainly to their permanent occupation of the land and consequent interference with normal crop production. If permitted to spread widely the cost of their extermination may easily become higher than the value of the land itself. Such weeds as leafy spurge *Euphorbia esula* L. *Galatrhoens esula* (L.) Rydb., hoary cress *Lepidium draba* L., field bindweed *Convolvulus arvensis* L., Russian knapweed *Centaurea repens* L., poverty weed *Iva axillaris*, Pursh., Canada thistle *Circium arvense* (L) Scop., perennial sow thistle *Sonchus arvensis*, L. and Quack grass *Agropyron repens* L. are particularly dangerous. Fortunately the most serious members of the noxious group are only in their initial stages of invading Canadian soils and therefore may and should be checked at the present time even if the cost of treatment is high. When the weeds are present in comparatively small patches chemical control becomes of first consideration. In this case, however, a clear understanding of the mode of chemical action in exterminating these pests is essential not only for the reason of reducing the cost of the treatment to a minimum, but also for the purpose of planning the work in such a manner as to assure complete destruction of plant roots irrespective of the depth of penetration.

So far the bulk of the experimental work on eradication of perennial weeds by chemicals has been carried on in an empiric way to determine the lethal quantity of the herbicides and the time and form of application for each species of weed under certain growing conditions. Just how these chemicals act to effect the death of the plant, however, has remained obscure. It was for the purpose of securing some experimental evidence on this particular question that this investigation was undertaken. The project included two separate but closely related studies, namely, (a) the mode of vegetative propagation and ecological adaptation of the roots of perennial weeds, and (b) the effect of herbicides on perennial weeds applied to the top growth alone, the soil being protected; to the soil only, the top growth being protected, and to both top growth and soil at the same time.

## EXPERIMENTAL PROCEDURE

Single plants of various species of perennial weeds were spaced from 6 to 40 feet apart and their root systems excavated at different stages of plant development. During the first season of growth the excavations were made when the plants were 1, 2 and 3 months old. In the second and third year only one excavation, usually late in September, was made. Roots of the plants grown in solid patches were carefully examined for several seasons.

In studying the lethal effect of the herbicides upon perennial weeds 7 chemicals were used; namely, sodium chlorate, arsenic pentoxide, acid

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sludge, alphanaphthylamine, tetralin, creosote and aniline. Each chemical was applied at 600, 750 and 900 lbs. to the acre. The chemicals which are readily soluble in water, such as sodium chlorate, were applied in water solution at a concentration of 1 pound to 2 gallons of water. The oily substances, such as tetraline, were first emulsified by adding sodium oleate or glue and then applied in the form of an emulsion of the same strength. When single plants were treated chemical solutions of the same strength were used and applied at the same rate as in the large plots.

The treatments were made at the bud stage and records taken after 1 day, 1 week, 1 month, before the fall freeze-up, during the first season, and twice during the year following the treatment.

Condition of the roots at various depths was determined by observation and viability tests in all the experiments. The thickness of the sterile layer of soil was ascertained by germinating Marquis wheat seed of known germinability in soil samples taken from the treated plots at depths from 1 to 36 inches below the surface.

## MODE OF VEGETATIVE PROPAGATION AND ECOLOGICAL ADAPTATION OF OF THE ROOTS OF PERENNIAL WEEDS

Before discussing the mode of chemical action in destroying perennial weeds it is desirable to understand in some detail the underground organs of the plants, the way in which they are propagated vegetatively, the functions performed by different parts of the root systems and certain adaptational responses to adverse environmental conditions. These will be considered briefly on the basis of experimental data during the course of these investigations before proceeding to the main subject under discussion.

With respect to the morphology of the subterranean parts perennial weeds may be conveniently divided into three major groups. The first group consists of grass species with perennial root crowns. The crowns produce numerous buds which serve as organs of vegetative propagation but their roots are fibrous and incapable of initiating new shoots. Wild barley *Hordeum jubatum* L. is a typical member of this group.

The second group embraces all the species which are provided with underground stems extending long distances from the point of their origin. These perennial organs are capable also of producing vegetative buds at every joint. The buds give rise to both the top shoots and the fibrous roots which support them. Quack grass *Agropyron repens* L., sweet grass *Hierochloe odorata* (L.) Wahlen b., and many other perennials, belong to this category.

The third group is composed of a large number of herbs with deep and profusely branched tap roots. Both the tap roots and their branches are thick mostly succulent perennial structures abundantly supplied with food reserves. A fact of still greater importance is that both are capable of developing meristematic centres almost at any point over their extensive length. These meristematic centres may give rise both to new aerial shoots and to new perennial roots. Canada thistle, poverty weed, hoary cress, field bindweed, leafy spurge, Russian knapweed and many other important weeds, belong to this class. This investigation was concerned mainly with some of the weeds of the third group.

It is not by mere accident that out of many thousands of plant species only a few have won the opprobrium of "noxious" weeds. They all possess the most amazing adaptational features which help them to survive and flourish in defiance of man's efforts to bring about their extermination.

Canada thistle, for example, provides an illustration of adaptation by developing two types of roots. Those in the first category (Type A) are produced either from stem tissue between the ground level and 6 to 7 inches in depth, or from root tissue at a depth of 11 or more inches below the surface. Both grow out horizontally only short distances from the points of origin and then turn downward to produce vertical roots. In each case shoots usually grow to the surface from the area where the bend in the roots occurs. These new shoots with their vertical roots then become detached from the mother plant and exist as independent individuals. The chief function of Type A roots is to firmly establish the species at or near the point of infestation.

The second kind of perennial roots of Canada thistle (Type B) is mainly concerned with the quick invasion of a new area. The runners of this type are usually located at depths of 7 to 11 inches below the surface and originate mostly from stem tissue. They spread laterally at a rate of 8 to 12 feet per season and their growing points seldom if ever turn downward to produce vertical roots. Instead they develop numerous top shoots to occupy quickly the freshly invaded ground.

Figure 1 shows graphically the mode of growth and the functions performed by the roots of types A and B. The numbers placed beside each root indicate the season in which the corresponding roots were produced after the original plant "O" was established. This 31 foot long runner "B" is a representative root of the second type as it appeared in the third season of growth.

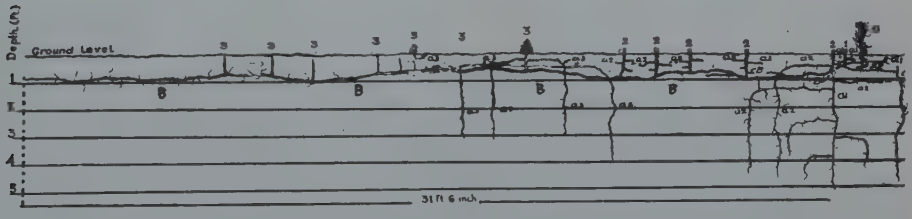


FIGURE 1. Three-year-old root system of Canada thistle. An exact chart of the roots (Types A and B) of a Canada thistle plant established from a 4-inch root cutting (S.P.) and excavated 3 years after planting. No's. 1, 2, and 3 designate the portions of the root system and top shoots which were produced in the 1st, 2nd and 3rd season of growth of the original plant "O."

Poverty weed also has two kinds of perennial roots but the special purpose which they serve seems to be different than that of Canada thistle roots. This is a striking case of specialization in performing the same function but under vastly different growing conditions. The shallow roots of poverty weed are very active only in good years. They effect the lateral spread, produce the top shoots and store great quantities of food reserves.

The deep roots of poverty weed, on the contrary, under similar conditions, remain comparatively inactive; they produce only occasional shoots in spite of a plentiful supply of food reserves. In dry years, however, they assume the all-important function of maintaining the species. From great depths (12 to 24 inches) they suddenly begin to grow upward. At approximately 2 to 4 inches from the surface they turn horizontally and produce several shoots, after which they turn sharply downward again and establish a vertical root to support the new plants. On account of this ecological adaptation the plants grow luxuriantly in years when all other species just barely exist or perish. They flourish in years of poverty, hence the name "poverty" weed.

In Figure 2, the shallow horizontal roots are marked "A." The numbers beside each root indicate the season in which they were produced after the mother plant became established from a cutting off a perennial runner.

The deep runners in Figure 2, are designated by the letter "B" with corresponding numbers showing the portion which grew each season. Unlike those of Canada thistle the poverty weed runners, both shallow and deep, always terminated with vertical roots. The latter are all marked "C" and the numbers indicate their age. On this chart one may easily notice that in dry years each deep root made a characteristic loop, came close to the surface, produced several shoots, and turned downward in the form of a new vertical root.

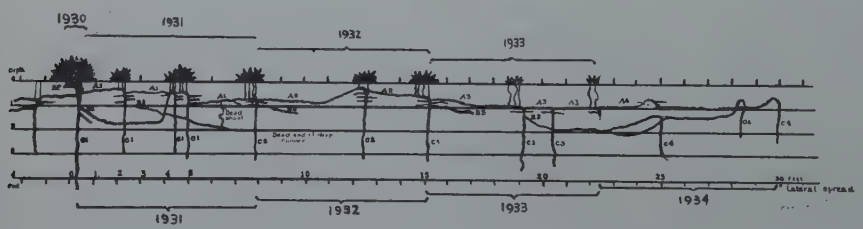


FIGURE 2. Four-year-old root system of poverty weed. Typical mode of growth and distribution of poverty weed roots excavated 4 years after the mother plant was established from a piece of perennial runner.

Another important adaptation very noticeable in the roots of poverty weed and some other species is the presence of strong corky or resinous layers in their bark. These protective structures are practically impermeable to water and thus protect the food reserves of the roots by reducing respiration in dry years and inhibiting decay in wet years. In dry seasons they help in the economy of water as long as the plant is active and effectively protect the latent life in the roots when they are forced to a long dormancy.

Species with roots that lack the external protection just mentioned, have other kinds of emergency adaptations. Canada thistle, sow thistle and hoary cress, for instance, in good years store considerable supplies of food and water in their succulent roots. In case of drought they quickly disassociate themselves from the mother plant and live independently at the expense of the food and water previously stored. These supplies are drawn first from the oldest portions of the root and directed toward the growing tips. In this manner the plants try to abandon the old patch

where moisture was seriously depleted to a great depth by the dense stand of weeds, and move to new areas in a search for more moisture. It is on this account that after a prolonged drought one may see ring-like patches, particularly of Canada thistle, with no vegetation in the centre and with a good stand of the weed in the periferial zones.

One more, and probably the most important characteristic, is that even the smallest sections of the roots may successfully establish new plants if the conditions are right. In many cases farmers themselves aggravate the situation by their eagerness to eradicate weeds without due consideration to the ability of their roots to regenerate new plants.

All these and many other features of the root system of perennial weeds are responsible for their persistance under cultivation. Any effective method for their eradication must be so designed as to counteract these traits.

In areas where the weeds are widely spread some form of tillage must be resorted to as the only practicable method of eradicating them. A tillage method for the complete eradication of quack grass, Canada thistle and sow thistle in one season, has already been described (3). There are, however, large areas in Western Canada where such weeds as leafy spurge, hoary cress, field bindweed and Russian knapweed are only in the first phase of invasion. They are as yet scattered in smaller and larger patches, and their further distribution may be effectively checked if the patches are located and the work of eradication undertaken in time. It is under these circumstances that herbicides may be used most effectively.

## MODE OF CHEMICAL ACTION IN DESTROYING PERENNIAL WEEDS

Numerous reports on field experiments from Europe, America and Australia suggest that chemicals provide the surest and cheapest method of exterminating the most harmful of the perennial weeds where they occur in small patches. The data, however, are based mostly on field observations and leave the problem as to the manner in which plants are killed by the chemicals altogether obscure. In general there are two different opinions on this question.

One opinion as to the mode of chemical action is that the chemicals in solution are absorbed by the foliage and circulated throughout the plant. According to this concept if the chemicals are applied to the top growth, the underground parts will eventually be killed also by internal circulation of the chemicals with the plant's sap.

Another opinion is that the plants are killed only by the action of the chemicals on the plant tissue with which they come in contact. It is therefore necessary to apply the chemicals both to the top growth and to the soil. Through subsequent leaching the chemicals will reach deeper and deeper strata of the soil and kill the plant roots on their way down.

The validity of these concepts was carefully tested in a field infested with Canada thistle.

A series of individual single-plant patches was treated with sodium chlorate, the soil being completely protected from the chemical. The result was that the top growth was dead in a few hours or days depending on the amount of the chemical used and the temperature of the atmosphere. When the leaves and stems were obviously dead the roots were excavated and their condition examined. It was invariably found that the root

systems were not killed. Occasionally the dead stems extended for about one-half to one inch below the line of the wax paper or rubber sheeting protecting the soil from the chemical. As early as 6 to 10 days after the treatment numerous new shoots were observed on the roots under the insulating material. A microscopic examination of the fresh root tissue taken from under the protective covering showed no evidence of the cell protoplasm having been coagulated or affected in any way by the chemical. In all cases the roots produced a new healthy top growth in 10 days after the covering was removed. These facts seem to disprove conclusively the assumption that the chemicals circulate from the foliage downward through the root system.

In another series of experiments only the soil was treated. Several concentrations of the chemical were used. It is interesting to note that when the concentration was low the chemical was caught by the transpiration stream and brought from the soil to the uppermost leaves. The regions next to the leaf veins were affected first, as shown by pale discolourations of the chlorophyll and coagulation of the cell protoplasm. Spots thus affected by the chemical gradually dried out, fused together and caused death of the entire leaf. Seldom, however, was an entire plant killed in this manner. Usually they were suppressed for a time and then began to recover.

When the chemical was applied to the surface soil in considerable quantity the top growth died in about two to three days without showing much evidence that the chemical extended into the tissues even a few inches above the soil surface. Also, no effects of the chemical on the roots were detected at depths greater than that to which the chemical was leached. These results clearly indicated that with strong concentrations the plant parts in direct contact with the chemical were killed quickly. No evidence was obtainable to prove that there had occurred any appreciable translocation of the chemical either upward to the foliage or downward in the roots. It is of interest to note that the conclusions arrived at by Chepil (1), working with sodium chlorate and perennial sow thistle under greenhouse conditions, confirm in general these findings from the field.

A third series of plots was treated by applying the chemicals to the top growth and the soil at the same time. Applications were made at three different rates and the plots were observed for several seasons. Tetraline and creosote did not kill completely the top growth of the weed at any time but the five other chemicals destroyed practically all the vegetation present. Detailed records from this experiment are given in Table 1.

It will be seen that in 30 days after treatment new shoots began to appear on some of the plots, and after one year they were abundant on all plots except those treated with sodium chlorate and arsenic pentoxide. It was then decided to examine the condition of the root material at various depths in all of the plots to determine the extent of the injury that had taken place and, if possible, the manner in which growth was inhibited.

Four months after the treatments root samples were taken in triplicate from all plots at 0 to 4, 5 to 8, 9 to 12, 19 to 22 and 25 to 28 inches in depth. In the greenhouse 20 three-inch cuttings of these roots from each sample were taken, planted in separate flats and tested for viability. The results are given in Table 2.

TABLE 1.—LETHAL EFFECT OF DIFFERENT CHEMICALS UPON CANADA THISTLE PLANTS

| Chemicals and rate of application in lbs. per acre | No. of plants per sq. yd. before treatment | Counts taken at various intervals after the treatment | | | | | | | | | | | | Plant population one year after treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 day | | | 7 days | | | 30 days | | | 100 days | | | |
| | | Dead leaves | Stems | New shoots | Dead leaves | Stems | New shoots | Dead leaves | Stems | New shoots | Dead leaves | Stems | New shoots | |
| | | % | % | No. | % | % | No. | % | % | No. | % | % | No. | |
| Sodium chlorate: | | | | | | | | | | | | | | |
| 600 lbs. | 31 | 80 | 17 | 0 | 100 | 52 | 0 | 100 | 97 | 2.6 | 100 | 98 | 1 | 0 |
| 750 lbs. | 31 | 95 | 25 | 0 | 100 | 80 | 0 | 100 | 98 | 1.3 | 100 | 100 | 0 | 0 |
| 900 lbs. | 33 | 100 | 28 | 0 | 100 | 92 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 0 |
| Arsenic pentoxide: | | | | | | | | | | | | | | |
| 600 lbs. | 30 | 100 | 28 | 0 | 100 | 98 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 3 |
| 750 lbs. | 30 | 100 | 40 | 0 | 100 | 98 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 0 |
| 900 lbs. | 30 | 100 | 38 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 0 |
| Acid sludge: | | | | | | | | | | | | | | |
| 600 lbs. | 27 | 100 | 80 | 0 | 100 | 100 | 0 | 100 | 100 | 38 | 100 | 100 | 48 | 63 |
| 750 lbs. | 31 | 100 | 88 | 0 | 100 | 100 | 0 | 100 | 100 | 47 | 100 | 100 | 59 | 61 |
| 900 lbs. | 32 | 100 | 98 | 0 | 100 | 100 | 0 | 100 | 100 | 46 | 100 | 100 | 57 | 65 |
| Alpha naphthylamine: | | | | | | | | | | | | | | |
| 600 lbs. | 26 | 75 | 0 | 0 | 100 | 32 | 0 | 100 | 83 | 15.6 | 100 | 98 | 28 | 47 |
| 750 lbs. | 26 | 83 | 0 | 0 | 100 | 43 | 0 | 100 | 97 | 20 | 100 | 100 | 44 | 51 |
| 900 lbs. | 30 | 85 | 0 | 0 | 100 | 52 | 0 | 100 | 100 | 24 | 100 | 100 | 48 | 49 |
| Aniline: | | | | | | | | | | | | | | |
| 600 lbs. | 21 | 62 | 10 | 0 | 90 | 62 | 0 | 90 | 82 | 2 | 90 | 82 | 28 | 56 |
| 750 lbs. | 20 | 70 | 10 | 0 | 98 | 82 | 0 | 98 | 98 | 3 | 98 | 98 | 17 | 42 |
| 900 lbs. | 22 | 87 | 13 | 0 | 100 | 97 | 0 | 100 | 100 | 7 | 100 | 100 | 27 | 46 |
| Tetralin: | | | | | | | | | | | | | | |
| 600 lbs. | 16 | 12 | 0 | 0 | 33 | 0 | 0 | 33 | 0 | 4 | 33 | 0 | 5 | 31 |
| 750 lbs. | 20 | 17 | 0 | 0 | 52 | 0 | 0 | 55 | 0 | 6 | 52 | 0 | 8 | 28 |
| 900 lbs. | 22 | 22 | 0 | 0 | 57 | 0 | 0 | 57 | 5 | 4 | 52 | 5 | 8 | 23 |
| Creosote: | | | | | | | | | | | | | | |
| 600 lbs. | 29 | 7 | 0 | 0 | 22 | 0 | 0 | 35 | 0 | 10 | 37 | 0 | 13 | 27 |
| 750 lbs. | 29 | 12 | 0 | 0 | 42 | 0 | 0 | 35 | 0 | 16 | 55 | 0 | 18 | 21 |
| 900 lbs. | 31 | 19 | 0 | 0 | 45 | 0 | 0 | 65 | 9 | 21 | 69 | 9 | 21 | 24 |

TABLE 2.—VIABILITY OF ROOT CUTTINGS OF CANADA THISTLE, TAKEN AT DIFFERENT LEVELS AFTER TREATMENT WITH CHEMICALS, AS A TEST OF SOIL STERILITY

| Depth of Sample in inches | No. of shoots obtained from different depths (60 cuttings) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sodium chlorate | Arsenic pentoxide | Acid sludge | Alpha-naphth-ylamine | Aniline | Tetro-line | Creosote |
| 0– 4 | 0 | 0 | 26 | 27 | 31 | 29 | 22 |
| 5– 8 | 0 | 3 | 33 | 36 | 31 | 38 | 38 |
| 9–12 | 2 | 39 | 39 | 34 | 34 | 37 | 33 |
| 19–22 | 11 | 14 | 18 | 23 | 18 | 22 | 24 |
| 25–28 | 8 | 7 | 6 | 9 | 7 | 6 | 8 |
| 37–40 | 1 | 2 | 2 | 1 | 1 | 3 | 0 |

The data in Table 2 proved definitely that the soil in the sodium chlorate plot was sterile at the time of this test at least to a depth of 9 inches. In the plot treated with arsenic pentoxide the sterility was obvious to a depth of 5 inches only. In all other plots the chemicals apparently were quickly neutralized and the soil was again in good fertility.

The next year the plots treated with sodium chlorate and arsenic pentoxide still remained free of vegetation of any kind while all others supported heavier stands of Canada thistle than before the treatment. It seemed desirable, therefore, to test further the layers of the soil in these two treatments with respect to the incidence and degree of sterility.

Excavations of the soil were made across the plots to a depth of 3 feet and careful observations on condition of the root material obtained at various depths recorded. These revealed the following facts:

(1) In the centre of each plot the root material was completely dead from the soil surface to the depth of excavation.

(2) For $3\frac{1}{2}$ feet inward from the border of the sodium chlorate plot the root material was dead within the top 11-inch layer of the soil only. The root material located deeper than 11 inches was perfectly fresh and healthy (see Figure 3).

FIGURE 3. Canada thistle twelve months after treatment with sodium chlorate. Diagram of a portion of the sodium chlorate plot showing, (1) an 11-inch deep layer of sterile top soil produced by an application of 900 lbs. of sodium chlorate to the acre (hatched), (2) dead roots to a depth of 3 ft. in the centre of the plot, but only to a depth of 11 inches in the periferial zones (black roots), (3) fresh roots growing under the sterile layer of the soil and producing numerous shoots, which are all killed as soon as they enter the sterile layer of the top soil, (4) a vigorous top growth next to the treated area.

(3) In the plot of arsenic pentoxide, at the same distance from the border, the root material was dead only within the first 6 to 7 inches from the surface. At greater depth the roots were all alive (see Figure 4).

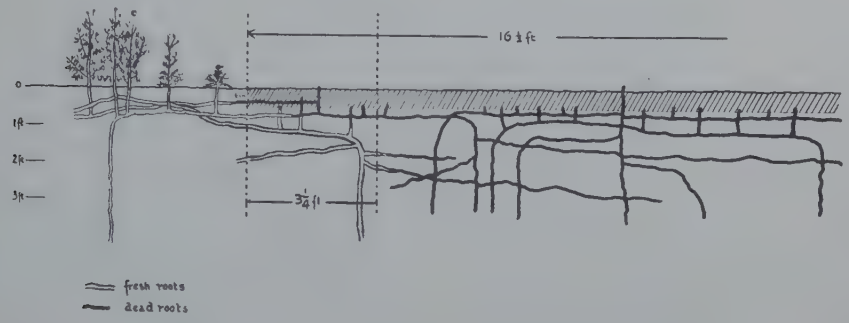


FIGURE 4. Canada thistle twelve months after treatment with arsenic pentoxide. A portion of the arsenic pentoxide plot illustrating exactly the same points as in Figure 3, but the thickness of the sterile top layer of the soil being only 6 inches.

From these results it was deduced that the sodium chlorate had sterilized the soil to 11 inches in depth while arsenic pentoxide had penetrated only 6 to 7 inches below the surface. The fact that the root material was dead to the full depth of 3 feet in the central areas of both plots, however, was a puzzle which had to be explained on some different basis than the direct action of the chemicals. To afford such an explanation it was necessary first to establish definitely the thickness of the sterile soil throughout the plots at this time. Therefore numerous soil samples were taken in both plots from 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 18, and 24 inch depths. The soil samples were placed in separate trays and a germination test with good Marquis wheat seed was made.

The results obtained from these tests are presented in Table 3.

TABLE 3.—DEPTH OF STERILE SOIL RESULTING FROM AN APPLICATION OF 900 LBS. PER ACRE OF SODIUM CHLORATE AND ARSENIC PENTOXIDE, AS INDICATED BY A GERMINATION TEST WITH MARQUIS WHEAT SEED

| Sodium chlorate | | | Arsenic pentoxide | | |
|---|---|---|---|---|---|
| Depth | Percentage germination | | Depth | Percentage germination | |
| in. | % | | in. | % | |
| 0– 1 | 0 | | 0– 1 | 0 | |
| 1– 2 | 0 | | 1– 2 | 0 | |
| 2– 3 | 0 | | 2– 3 | 0 | |
| 3– 4 | 0 | Total sterility | 3– 4 | 0 | Total sterility |
| 4– 5 | 0 | | 4– 5 | 0 | |
| 5– 6 | 0 | | 5– 6 | 0 | |
| 6– 7 | 0 | | 6– 7 | 2 | |
| 7– 8 | 0 | | 7– 8 | 5 | Partial sterility |
| 8– 9 | 0 | | 8– 9 | 68 | |
| 9–10 | 0 | | 9–10 | 93 | |
| 10–11 | 3 | | 10–11 | 96 | |
| 11–12 | 58 | Partial sterility | 11–12 | 96 | |
| 18–19 | 96 | | 18–19 | 98 | |
| 24–25 | 87 | | 24–25 | 91 | |
| | | No sterility | | | No sterility |

## DISCUSSION OF RESULTS

The results from the experiment where only the foliage of the weeds was treated prove conclusively that the chemicals which killed the aerial parts was not transported to the root system. This was to be expected since translocation, either up or down, through the conducting tissue of the plant is possible only as long as the protoplasm remains alive. That this may occur if the rate of application is sufficiently light was shown in a separate test where the chemical was used at a rate of 1/10 of a pound per 100 sq. feet or 45 lb. per acre. At this low concentration the chemical, as a component part of the soil solution, was taken in by the roots and transported to the uppermost leaves. At first no injury to the plant was observed, but in two or three days' time the tiniest leaf veins and youngest leaves began to show pale spots. In the hot sun these quickly dried out, fused together and many of the leaves died. Others, especially the older ones, remained palish green for a long time but finally recovered and resumed a normal appearance.

This raises a question, which remains unanswered, whether there may be a critical concentration of the chemical in the soil solution which would be weak enough to permit the latter to pass upward through the plant but strong enough to eventually destroy the plant completely. It seems altogether unlikely that such a concentration could be determined, and even if it were found the information would be valueless for purposes of weed eradication since there could be no practical means of controlling the concentration of the chemical in the soil solution.

Examination of the roots to a depth of 3 feet one year after treatment showed that they were dead not only within the layer of soil which had been impregnated by the chemical solution, but also below the zone of penetration. A satisfactory explanation of the latter presented some difficulty, especially in view of the fact that these plants are deep-rooted, frequently extending 15 feet or more below the soil surface.

The theory that weeds are destroyed by chemicals only when the latter come into direct contact with the plant tissues was easily shown to be invalid. Treatments with sodium chlorate and arsenic pentoxide resulted in the complete eradication of Canada thistle notwithstanding the fact that the chlorate had not penetrated beyond 11 inches and the pentoxide below 7 inches in depth. An examination of both the roots and the soil from below these levels never showed any indication of the presence of the chemicals.

Since the deeper roots were not killed through direct action of the chemicals, either by surface contact or by circulation with the cell sap, it is a reasonable assumption that they perished by suffocation and exhaustion of their food reserves because of the presence of the sterile layer of top soil (2). This conclusion is borne out by the fact that around the periphery of the treated area for about 3 feet inward those roots located below the sterile layer of soil and attached to plants outside the treated area, were all alive. They produced numerous shoots, but all of these were killed when they tried to enter the sterile layer of top-soil. Only after they were finally depleted of their food reserves did they begin to die off (see Figures 3 and 4).

The logical conclusion, therefore, is that the herbicides effect eradication of perennial weeds indirectly by producing a sterile layer of soil which inhibits top growth for a period of at least one year. In this respect there is no material difference between the mode of chemical action and that of continuous surface tillage in killing the subterranean organs of perennials. Large patches of Canada thistle and sow thistle were hoed at frequent intervals from July 1 to the end of the growing season to prevent new shoots from emerging above the soil surface. In another test the weeds were removed and the ground covered tightly with waxed paper during the same period. Upon examination of the root systems of these weeds in October no viable roots were found of perennial sow thistle and only small bits of perennial runners showing weak signs of life were detected in Canada thistle. The next year the land was entirely free of the weeds in both cases. The similarity of the results by these methods with those obtained by the use of sodium chlorate and arsenic pentoxide is striking.

It would appear also that the efficiency of a chemical as a herbicide will depend not only on the sterilizing effect which it has on the soil but also on the length of time it will maintain its stability in the soil after being applied. This is evidently much more important than its corrosive effect on organic matter. Acid sludge for example, was the most corrosive among the 7 chemicals tested, but it failed completely to eradicate the weeds because it was quickly neutralized in the ground, and therefore did not produce a lasting sterility of the top soil.

Finally it would seem that only enough chemical need be used to create a sterile layer of soil of a few inches. It is better therefore to apply the solution in fairly concentrated form rather than use a weak solution applied in greater quantity. The amount of water, and hence the concentration, should be governed, within limits, by the moisture content of the soil, providing always that the amount of water is sufficient to permit of an even distribution.

## SUMMARY

1. The subterranean parts of all perennial plants possess morphological features which enable them to produce quick vegetative multiplication in case of environmental disturbances threatening them with extermination.

2. Many species, in addition to these morphological features, have acquired highly specialized ecological adaptations to enable them to survive under adverse climatic conditions.

3. There is no experimental evidence in support of the claim that chemicals in solution of herbicidal concentration may circulate throughout the entire plant system if applied to the foliage and result in their extermination.

4. Only very weak solutions, not lethal to the plant organism, may be absorbed by the roots and transported to the foliage without killing the entire plant.

5. In no case were chemicals transported through the plant system downward into the roots located below the level of actual leaching of the chemical into the soil.

6. There is conclusive experimental evidence from this work that chemical herbicides eradicate perennial weeds not by direct destruction of all subterranean organs but indirectly by producing a durable sterility of the top soil which prevents aerial growth until the underground parts not in contact with the chemicals, perish of suffocation and starvation.

7. In this respect chemical herbicides effect the death of perennial weeds in the same manner as does continuous surface tillage, inhibiting new growth above the surface.

8. The efficiency of a herbicide depends on the sterilizing effect which it has on the soil and the maintenance of that sterility for a period of time sufficient to destroy the subterranean organs of the plant.

## ACKNOWLEDGMENT

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# SEEDLING BLIGHT OF CARROT CAUSED BY *ALTERNARIA RADICINA*[1]

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A black rot of stored carrots found in New York, Massachusetts, Pennsylvania and the District of Columbia, was studied by Meier, Drechsler and Eddy (5). The causal organism was isolated and after comparing it with *Macrosporium Carotae* Ellis and Langlois, it was described as a new species, *Alternaria radicina*. Lauritzen (4) found black rot of considerable importance in the decay of stored carrots in the United States. He studied the mode of entrance, temperature range for infection and for growth of the fungus in culture, and tested 17 varieties of carrots for susceptibility. Recently Ramsey and Wiant (8) have published an excellent colour photograph of the disease as it appears on carrot roots, accompanied by a concise description of occurrence, symptoms and effects. According to Neergaard (6) black rot has been found in Germany and Denmark, and Ogilvie (7) suggests that a black rot recorded several times in Great Britain may be identical with the disease found in United States. Black rot has been found on field carrot at Saanichton, B.C. and by W. Jones on overwintered garden carrots at New Westminster, B.C., but it is not of common occurrence.

Doyer (2) reported the presence of *A. radicina* on carrot seeds, described and illustrated its appearance on infected seedlings in a germinator (3), and remarked that "this infection as it remains superficial can be very well controlled by treating the seed".

Neergaard (6) not only found *A. radicina* on carrot roots but on celery, parsnip and rooted parsley, and in germinators on carrot, celery and rooted parsley seedlings. He studied the organism in culture, its morphology and temperature requirements, the latter agreeing closely with results previously published by Lauritzen (4), and inoculated both celery seedlings and older plants. He reports as follows on the examination of a number of lots of carrot seed in Denmark: "In the spring of 1935 a lot of carrot seeds St. Valery of 730 kg. proved to have a germinating capacity of about 62%, of which about 32% was attacked by *Alternaria radicina*. In October-December, 1935, attacks were found on carrot seedlings in Jacobsen's germinator of 26 different lots of seeds of the following varieties: Amager, Amsterdam, James Scarlet Intermediate, James Scarlet Long, Chantenay, Nantes, Odense Market, Butter Carrot".

Recently in greenhouse tests of carrot seed for seed-borne organisms *Alternaria radicina* has been found to be responsible for most of the seedling blight which occurred. There appears to be no previous published record of its occurrence as a seedling blight in North America. During the last two years 28 samples of carrot seed have been grown in the greenhouse in

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steam sterilized soil. The seeds were evenly spaced and planted 100 seeds to a flat. The seedlings were kept at least until the first true leaves appeared. Fourteen samples of seed produced in 1940 were either entirely free or showed a negligible amount of seedling blight due to *A. radicina*. Of 14 samples of 1941 seed only 5 were free or nearly so, 6 developed 14–18% *Alternaria* seedling blight and of the remainder one developed 22%, one 27% and one 40% blight. In that year weather conditions during harvesting of the seed were unusual and most unfavourable and this appears to be directly reflected in the increased amount of *A. radicina* present in the seed samples.

In carrot seedlings infected by *A. radicina* the hypocotyl and root become dark brown or black and shrunken, and the plant may fall over while the leaves are still green; later they shrink and turn brown (1). If infected seedlings are removed and placed in a moist chamber, typical mycelium and spores of *A. radicina* are produced (5, 6). The fungus may be cultured readily and on malt agar produces a dense mat of dark greenish black mycelium similar to that which develops on infected carrot roots under moist conditions (8, pl. 12; 4, Figure 1). Using as inoculum cultures isolated from infected seedlings and following the method outlined by Meier *et al.* (5) typical black rot has been produced in surface sterilized carrot roots (Figure 1) and typical seedling blight on healthy young carrot seedlings.

FIGURE 1. Black rot in carrot roots 12 days after inoculation with mycelium of *Alternaria radicina* isolated from diseased carrot seedlings. Control at left. Root was surface sterilized and incisions made but no inoculum used. Photograph by J. M. McArthur.

Doyer (3) found seed treatment satisfactory, Neergaard (6) obtained control by immersing the seed for one-half, one, or one and one-half hours in $\frac{1}{4}\%$ germisan, $\frac{1}{4}\%$ Sanagran or $\frac{1}{4}\%$ Uspulun.

In most of our experiments with seed treatments the seed sample which had yielded 40% of seedlings infected with *A. radicina* was used. Seeds to be treated were placed in a vial and after a small amount of dust had been added, were shaken vigorously then the excess dust was sifted off by using a small strainer. The treated seeds, together with untreated samples as checks, were sown in sterilized soil in the greenhouse. Almost complete control was obtained by treating the seed with Semesan Junior (1% ethyl mercury phosphate), with New Improved Ceresan *diluted* to contain 1% ethyl mercury phosphate, or with Spergon (tetrachloroparabenzoquinone).

## SUMMARY

Seedling blight and black rot of carrot caused by *Alternaria radicina* Meier, Drechs. and Eddy, are reported from British Columbia. Black rot developed in roots inoculated with mycelium isolated from infected seedlings. The disease is seed-borne but readily controlled by seed treatment.

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# SUPERSEDURE OF QUEENS IN PACKAGE BEES

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## INTRODUCTION

The extensive increase in the importation of package bees into Canada during the 1930's accentuated the importance of the supersedure of queens problem. The losses of queens through supersedure in commercial or side-line apiaries ranges from 20 to 100% per annum. The cost of replacement queens, the retardation of colony build-up prior to the main honeyflow, the reduced yields and consequent lowered financial returns affected sufficient beekeepers to warrant a detailed study of the problem from the receivers' end.

In the fall of 1934, the Dominion Apiarist, Mr. C. B. Gooderham, outlined an experiment for the purpose of ascertaining to what extent the manner of installation might bear on the problem. Five methods (A, B, C, D, and F) were tried in 1935, four more (G, H, I, and J) were added in 1936, and one method (K) was added in 1939. Four colonies were used in each method every year, consequently 20 packages were purchased in 1935; 36 in 1936, 1937, and 1938; and 40 in 1939, 1940, and 1941. All of these packages, with the exception of those in method J, were purchased from the same southern shipper throughout the experiment. The packages were relatively uniform in the age and number of bees which they contained. The queens, in all probability, were sister queens mated under similar conditions. The only variable factor was the manner in which packages or queens were handled after being consigned and on arrival at their destination. All of the packages (2-pound) were received on the one date each year and generally during the same week in each of the 7 years. Method J was a co-operative project between Dr. J. E. Eckert of the University of California and this Farm. The California packages contained 3 pounds of bees and fall reared queens of known parentage, on the mother's side. These queens were painted and clipped prior to shipment.

## METHODS

The package bees on arrival had their screens painted with sugar syrup, then they were stored in a cool, dark cellar. Extremely cold, wet, or unfavourable weather frequently delayed hiving the packages one or two days after arrival. The screens of the stored packages were painted with sugar syrup at 7.00 a.m., 1.00 and 6.00 p.m. every day until hiving took place. The hiving was generally performed in the late afternoon, when the majority of over-wintered colonies had suspended their flight activities. The following paragraphs outline the methods used for hiving the package bees and queens and the subsequent treatments applied after hiving had been completed. The queens were shipped unattended unless otherwise noted:

[1] Assistant to Superintendent, Apiculture.

A—The hives were prepared with 1 comb of honey, 1 comb of pollen, and 1 comb containing open brood from an over-wintered colony. The openings in the queen cages were filled with candy, and the queen cages suspended between the combs of open brood and pollen. One-third to one-half of the bees were shaken from the packages over the combs and queen cages. The packages with the remaining bees were set in the open space in the hives and the whole covered with bags to conserve the heat. The hive covers were put into place, and the hive entrance reduced to $\frac{3}{4}$ inch in length. Except to remove the empty packages the following day, and to see that the queens were released within 48 hours, these hives were not disturbed for the next 7 days. The remaining 7 drawn combs were placed into the hives at the first regular examination.

B—The second group of hives was prepared with 2 combs of honey, 1 comb of pollen, and 7 drawn combs to each hive. All the bees were shaken from the packages into the hives, the queens were released from the queen cages and allowed to run into the hives from the reduced entrances. These hives were not disturbed for the next 7 days.

C—The third group of hives was prepared with 2 combs of honey, 1 comb of pollen, and 7 drawn combs to each hive. Bags were spread out on the ground at the entrances. The bees were shaken out of the packages, over the opened queen cages, in front of the hives, and allowed to run in. After the bees had entered, the hive entrances were reduced and the colonies were not further disturbed for 7 days.

D—This group of hives was prepared in a manner similar to method A, with the exception that one extra comb of honey was used to replace the frame of open brood; but the manner of hiving was identical to method A. Three weeks after releasing the package bees, 2 frames of emerging brood from over-wintered colonies were added to each of the colonies in this group.

F—In this method the group of hives was fitted with a full complement of drawn combs, 2 of which contained honey and 1 pollen. The queen cages, stoppered with candy, were suspended between the combs in the broodchamber. An empty super was placed on top of the broodchamber and the packages of bees, with covers and feeder tins removed, were inverted over the tops of the frames, immediately over the queen cages, in the lower broodchambers. Bags were tucked into the vacant space around the packages in the supers, covers were put into place and the entrances reduced. The following day the packages were removed from the super and the hives were not disturbed for 7 days.

The following methods were added in 1936.

G—The hives in this method were prepared in the same manner as in method F. The 2-pound packages were shipped without queens and the queens (attended) forwarded by mail. All the bees were shaken from the packages into the hives and the travelling queen cages suspended between the frames. With the exception of seeing that the queens were released in 48 hours, these hives were not disturbed for the next 7 days.

H—These hives were prepared in the same manner as those in method D. The queen cages were supplied with a special pollen candy and the queens accompanied by attendants. The queen cages were suspended between the frames, and a small number of bees were shaken out of the

packages over the combs and the queen cages. The packages with the remaining bees were set in the open space in the hives and the whole covered with bags to conserve the heat. Except to remove the empty packages and see that the queens were released in 48 hours the hives were not further disturbed for the next 7 days. The remaining 7 drawn combs were placed into the hives at the first regular examination.

I—The hives were prepared and the manner of hiving was the same as in method B. These hives were placed beside weak, over-wintered colonies. Three weeks after hiving the packages, the queens in the over-wintered colony united with the package colony, which was placed on the stand formerly occupied by the over-wintered colony.

J—At the suggestion of Dr. J. E. Eckert, University of California, Davis, California, four 3-pound packages with tested queens, reared the fall previous, were sent from California to be included in this experiment. These packages were treated the same on arrival as the 2-pound packages. The preparation of the hives and the manner of hiving was the same as in method B.

K—This method was started in 1939. The hives were prepared with frames of foundation and supplied with sugar syrup for feed. The bees were shaken from the packages into the hives and the queens allowed to run into the hives at the reduced entrances. These hives were not further disturbed for the next 7 days except to supply syrup as required.

## RESULTS

### *Hiving the Bees*

Table 1 outlines some of the pertinent hiving data which were obtained for the duration of the experiment.

TABLE 1.—HIVING PACKAGE BEES 1936 TO 1941

| Year | Source of package bees | Date of arrival | Date of hiving | Time interval during hiving | Temperature at the start and finish of hiving | Minimum temperature the following night |
|---|---|---|---|---|---|---|
| | | | | | °F. | °F. |
| 1935 | Alabama | May 5 | May 9 | 4.15 – 6.00 p.m. | 45 – 45 | 26 |
| 1936 | Alabama | May 7 | May 9 | 3.30 – 6.45 p.m. | 77 – 68 | 37 |
| | California | May 16 | May 18 | 4.30 – 5.00 p.m. | 56 – 56 | 30 |
| 1937 | Alabama | May 15 | May 15 | 3.45 – 5.20 p.m. | 62 – 58 | 36 |
| | California | May 3 | May 4 | 3.45 – 4.00 p.m. | 71 – 71 | 43 |
| 1938 | Alabama | May 6 | May 7 | 3.00 – 4.45 p.m. | 51 – 49 | 24 |
| | California | April 30 | April 30 | 4.00 – 4.15 p.m. | 72 – 72 | 38 |
| 1939 | Alabama | May 4 | May 6 | 3.15 – 5.45 p.m. | 67 – 67 | 46 |
| | California | May 1 | May 1 | 4.00 – 4.15 p.m. | 83 – 83 | 51 |
| 1940 | Alabama | May 3 | May 3 | 6.00 – 8.20 p.m. | 64 – 59 | 40 |
| | California | April 23 | April 23 | 4.00 – 4.30 p.m. | 64 – 40 | 26 |
| 1941 | Alabama | April 30 | May 1 | 3.30 – 6.00 p.m. | 56 – 58 | 47 |
| | California | May 5 | May 5* | 3.55 – 4.05 p.m. | 54 – 54 | 46 |

* Raining when hived.

In method C the time required for the bees and queens to enter the hives was recorded, and Table 2 outlines the time intervals in minutes from the time hiving commenced until the bees or queens were all in the hives.

TABLE 2.—METHOD C. TIME INTERVAL IN MINUTES FOR QUEENS AND BEES TO ENTER HIVES

| Year | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 |
|---|---|---|---|---|---|---|---|
| Queens | | | | | | | |
| 1 | 7 | 5 | 7 | 20 | 17 | | 19 |
| 2 | 7 | 5 | 7 | 20 | 20 | All | 19 |
| 3 | 7 | 5 | 5 | 7 | 20 | Queens | 10 |
| 4 | 7 | 5 | 5 | 7 | 7 | Released | 10 |
| Bees | | | | | | in | |
| 1 | 15 | 15 | 15 | 20 | 15 | Hives | 22 |
| 2 | 15 | 15 | 15 | 20 | 10 | on | 17 |
| 3 | 15 | 15 | 15 | 15 | 20 | Founda- | 15 |
| 4 | 15 | 15 | 15 | 15 (smoked) | 7 | tion | 13 |

N.B.—In 1935 two queens ascended the front of their hives but entered shortly afterwards. In several instances the queens have remained outside of the hive after the majority of the bees had entered (1939–1940).

Nothing unusual or worthwhile recording occurred while the bees were being installed by the various methods. Flight conditions, immediately after hiving, varied depending upon the temperature, time factors, etc., but on the whole very little drifting occurred during the operation. The bees in the queenless packages (G) were quiet on arrival and behaved in a similar manner to queen-right packages during the hiving period. The number of dead bees in the queenless packages varied in each package and also between each season. The number of dead bees in the queenless packages was equal to that of the queen-right in 1936; greater in 1937, 1938, and 1939, but less in 1940 and 1941.

An outbreak of disease in the apiary in 1939 necessitated a modification of the methods in this experiment in 1940. Frames of foundation replaced drawn comb, and queen excluders were inserted between the bottom board and broodchamber to prevent the bees absconding. Sugar syrup (ratio 2–1) was substituted for frames of honey as spring feed and pollen stores had to be gathered from the fields when available. In 1941 drawn comb was used but sugar syrup was used for feeding.

*Movement of Bees from the Cages.*

The majority of the bees moved from the packages to the combs during the night in methods A and D, but considerable difficulty was experienced in methods F and H. In 1935 more and in some instances less than one-third of the bees in the cages in method F had moved onto the combs, preferring to remain tightly clustered in the packages until the following morning. The four queens were severely chilled and on examination appeared dead, but they revived in the operator's pockets and were re-inserted into their respective hives after the bees had been shaken from the packages. The queens were all accepted and no supersedure attempts were noted in these colonies during the summer. Method F had one

package with one pound of bees remaining inside the following morning in 1936, in 1937 there were 5% in each of the 4 packages, in 1938 and 1939 there were 2%, and 30 per cent in 1940. Method H had 1% and 2% respectively remaining in the cages over night in 1938 and 1939.

The manner of installation as practised in method "B" would appear to be the most satisfactory for the commercial beekeeper. No second visit to remove the package or queen cage is necessary and in the majority of cases the queens were laying regularly 1 hour after being liberated. Method D, or the method of hiving specifically outlined by the shipper, is perhaps the best method of installation for the beginner to follow.

*Introduction of Queens*

The manner of introduction has been outlined under the various methods. In all cases except G and H the queens were shipped unattended by worker bees. This necessitated the insertion of a small piece of queen-cage candy into the cork stoppered opening in all methods where the queen cages were inserted between the frames. In methods G and H the regular sized wooden queen mailing cages were used and a hole was poked through the candy with a nail or pencil before the cages were inserted between the frames. Table 3 shows the annual loss of queens through introduction and supersedure in each method, and indicates that queens were lost through the former in all methods except H, but none escaped loss from supersedure. Frequently non-accepted, dislodged queens were located in front of the hives and the time interval varied from 12 hours to 5 days from the time of hiving. The rejected queens, in the majority of instances, appeared normal in all respects. Occasionally they had been stung in some portion of their legs, or the wings were badly frayed, indicating that the queen had been balled after being released. However, in a number of cases where the queens had been accepted, they had been stung, as evidenced by paralyzed legs, or their wings had been frayed by chewing, but these apparently injured queens continued to head colonies throughout the summer without any apparent ill effect. The following recorded observations by methods outline some factors which could not be included in the Table.

Method A—In 1938 two queens were dead in the cages at the time of hiving and as no other queens were immediately available, these dead queens were inserted between the frames and the package bees hived as outlined. The dead queens were removed and laying queens introduced one week later, after destroying all queen cells started on the frame of open brood.

Method B—Laying workers had developed in one colony in this group in 1936 before the first regular examination after hiving. However, a young laying queen was introduced, accepted, and no further trouble was experienced in that particular colony. One package with a dead queen on arrival in 1938 was handled in the same manner as in method A. In 1940 the queens were run among the bees, after the latter had been shaken into the hive.

Method C—One queen in 1939 was tightly balled at hiving time, and the bees were attempting to remove her body from the hive entrance on May 13. No eggs had been laid by this queen. In 1940 the queens

were dipped in syrup and run among the bees, after the latter had been shaken into the hive. One queen became a drone layer 2 weeks after being introduced. The body of a second queen could not be located in front of the hive entrance or on the queen excluder which had been placed between the bottom board and the broodchamber.

Method D—In 1937 one colony in this group killed its introduced queen. Examination revealed the presence of a virgin queen among the package bees; the latter, however, never became mated and the colony had to be requeened. One queen, in 1940, was being balled when the hive was examined 1 week after hiving, and no trace of this queen could be found 2 days later.

Method F—With the exception of the chilling of queens in 1935 as outlined under the heading of "Hiving the Bees", nothing unusual occurred in this method.

Method G—The attended queens, shipped by mail, generally arrived on the same day as the packages, occasionally a day ahead and only once a day after the packages; fortunately in the latter instance the package bees could not be hived on the day of their arrival. Two days after the package bees had been hived, the queen cages would be examined to see if the queens were released and if not the opening in the candy was enlarged sufficiently so that the bees could readily release the queens. Laying workers developed in 1 colony in this group in 1936, similar to method "B", but in this colony the regular queen was accepted and began to lay regularly. In 1937, none of the queens in this group were released from the travelling queen cages 7 days after hiving. A thorough examination of all these colonies failed to show the presence of loose or stray queens being present. However, all 4 colonies showed the presence of eggs, irregularly placed, in worker cells, varying from a few eggs in 3 of the colonies to approximately one-quarter of a frame full of eggs in the fourth colony. The egg areas were marked for future observations regarding their fertility and then the queens were released on the frames. Two of the queens readily joined the bees in their hive. One queen was balled shortly after entering the cluster and she was picked out of the balling mass and allowed to run in at the entrance. Ample puffs of smoke preceding and following her entrance probably aided her acceptance. The fourth queen flew into the air when released, circled and came back to the hive several times, alighted, then took wing again but finally she walked down between the frames and was accepted by the bees. Seven days later all the queens were laying regularly. The egg areas marked for observation developed into worker larvae and adult bees. One queen had emerged from the queen cage 7 days after hiving in 1939. Her left hind leg was paralyzed and she had laid no eggs. A week later she was laying regularly. The remaining 3 queens were run in at the entrance and all were accepted by the bees. The egg transfers were similar to those of 1937. In 1940 none of the queens were released on May 8, five days after hiving, but they were all accepted and laying regularly by May 17. Nothing unusual occurred in 1941 in this group.

Method H—The candy used in these queen cages was a special pollen candy forwarded to the shipper for use in the travelling queen cages. These

queens came attended every year except in 1938 and nothing unusual happened during the introductory period. Occasionally the candy was very hard and at times too soft.

Method I—Laying workers developed in 1 colony in 1936 similar to those recorded under methods B and G. Nothing unusual happened until 1940 when the queens were dropped among the bees after the latter had been shaken into the hive. No trace of the queen could be found in 1 colony either above or below the excluder or in front of the hive. In a second colony the queen had her right hind leg paralyzed on introduction but she continued to head the colony until fall. In 1941 one queen was not accepted because of the presence of laying workers among the package bees. A second queen introduced to this colony was killed in the introduction cage.

Method J—The queens were shipped in Pinaud's cages, unattended in 1936, so the queen cages were suspended between the frames and the queens released 2 days later. In 1937 and 1938 the queens were shipped unattended and they were run in at the entrance. The queens were shipped loose among the package bees in 1939 and some additional queens suspended in the cages. One of the caged queens was killed and 2 of the loose queens were killed after the packages were hived. In 1940 the loose queens were all accepted and the 2 extra caged queens arrived in good order. The queens were all attended in Pinaud's cages in 1941 and all were accepted after being run in at the entrance.

Method K—The queens were all accepted in 1939 and 3-day old larvae were present in these colonies 7 days after hiving. One queen had her right front leg paralyzed on introduction so she was replaced. In 1940 the queens were dipped in syrup and dropped in among the shaken bees. All queens were accepted but 1 queen was found below the queen excluder (used in 1940) after the first examination. The queen excluder was reversed and the queen was found dead on the bottom board, another could not be found, while a third queen had her right hind leg paralyzed.

Queens introduced, as in methods B and C, were frequently laying eggs within 1 hour after the packages were shaken into the hive. Emerging bees were observed in such colonies on the twentieth and twenty-first day after the packaged had been hived.

*Painting and Clipping Queens*

To insure that supersedure did not take place unobserved, all queens in this experiment which had not been previously treated, were painted on the thorax, 3 weeks after the packages had been hived. The paint pigments were mixed in alcohol and ether to provide a rapidly drying mixture. A different coloured paint was used each year. The paint was applied with a camel's hair brush either when the queens were on the move over the combs or when caught and held by the wings. These markings made them readily noticeable and reduced the time required in examining broodchambers. Furthermore, all these queens had their right or left wings clipped before they were painted so that swarms could not leave unobserved. In the majority of cases the wings could be clipped without catching the queen, but where they were nervous, they were caught, held gently by the thorax and clipped. In 1935, 1936, and 1937, one queen only

had to be caught for clipping purposes. However, 2 queens were accidentally poked with the sharp point of the scissors but no adverse results were apparent throughout the season. In 1938 and 1939 no queens were caught for either clipping or painting. Several queens, however, were badly daubed, spreading paint over the wings and abdomen. No adverse effect was observed from this overdose of colour. One queen in 1939 had her right left leg paralyzed after the clipping and painting. In 1940 the majority of queens were caught in the hand for painting and clipping. Several queens squirmed and daubs of paint covered the compound eyes; none of these queens showed any adverse effects. One queen lay inactive on her right side while the bees tried frantically to remove the paint, then she moved forward a short distance and the same procedure was continued; however, at the next examination she was functioning normally. One other queen was dead at the examination following clipping and painting. In 1941 six queens were clipped without catching; the remainder were caught, clipped, and painted. Nine were caught between the index finger and the thumb, and 19 were caught by one pair of wings. The latter method was more rapid and no adverse effects were noted from this method of handling. The bees removed all of the paint from 1 queen which had been daubed over part of the abdomen and thorax. One queen was dropped 6 feet (accidentally) after clipping, another tried to sting her hind leg, and one which was in the act of laying an egg when clipped, walked lopsided, rested, continued on her side, and then stood erect. None of these queens appeared to be affected adversely at the next examination. One additional queen, however, had her right middle leg paralyzed.

*Broodchambers, Supers, etc.*

Congestion in the broodnests of the developing colonies was avoided as much as possible by supplying a supplementary deep broodchamber, and frames of honey and pollen were exchanged with empty frames from the supers when necessary. The presence of eggs and larvae and capped queen cells was carefully recorded. An attempt to distinguish between swarm and supersedure cells was made, on the basis of the location of the cells on the comb. The incidence of actual supersedure, recorded according to the various methods, is outlined in Table 3. The annual yields of honey are also given for the purpose of comparison. It should be noted that numerous instances were recorded where larvae were present in queen cells or where fully capped supersedure cells were present (one capped queen cell allowed to remain when present) in the colonies but supersedure did not take place. Occasionally capped queen cells were torn down and no further attempts at supersedure were noted in that particular colony. In 1938 and 1941 two or three virgin queens were observed in the colonies. None of these were mated and in one instance a second virgin queen emerged and did not get mated; consequently the original queen continued to head the colony for the remainder of the year. Such instances as noted above were not included in the supersedure summary because supersedure did not actually take place. Several instances were noted where mother and daughter laid eggs side by side for a period of 3 to 6 weeks before the original queen disappeared. The following table outlines the loss of queens on introduction, loss of queens through supersedure, and the honey production for each group for the years 1935 to 1941 inclusive.

TABLE 3.—SUMMARY—SUPERSEDURE OF PACKAGE QUEENS—1935 TO 1941

| Year | Total number of colonies in experiment | Method | | | | | | | | | | Total | Per cent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | F | G | H | I | J | K | | |
| **Queens lost on introduction** | | | | | | | | | | | | | |
| 1935 | 20 | 0 | 0 | 1 | 0 | 0 | | | | | | 1 | 5.0 |
| 1936 | 36 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | | 5 | 13.8 |
| 1937 | 36 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | 1 | 2.7 |
| 1938 | 36 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | | 3 | 8.3 |
| 1939 | 40 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 4 | 10.0 |
| 1940* | 40 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 4 | 10.0 |
| 1941 | 40 | 2 | 4 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 2 | 11 | 27.5 |
| Total | 248 | 3 | 6 | 4 | 4 | 2 | 2 | 0 | 4 | 2 | 2 | 29 | 11.7 |
| **Queens lost on supersedure** | | | | | | | | | | | | | |
| 1935 | 20 | 0 | 1 | 3 | 2 | 0 | | | | | | 6 | 30.0 |
| 1936 | 36 | 1 | 3 | 0 | 1 | 0 | 2 | 1 | 2 | 1 | | 11 | 30.5 |
| 1937 | 36 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | | 4 | 11.1 |
| 1938 | 36 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 0 | | 6 | 16.6 |
| 1939 | 40 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 5 | 12.5 |
| 1940* | 40 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 6 | 15.0 |
| 1941 | 40 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 12.5 |
| Total | 248 | 3 | 7 | 8 | 4 | 1 | 4 | 2 | 9 | 4 | 1 | 43 | 17.34 |
| **Honey Production in pounds** | | | | | | | | | | | | | |
| 1935 | 20 | 324.75 | 416.25 | 217.50 | 434.00 | 444.75 | | | | | | 1837.25 | Average 91.86 |
| 1936 | 36 | 1100.50 | 654.00 | 1189.00 | 988.50 | 1017.00 | 1073.50 | 868.50 | 844.00 | 729.00 | | 8464.00 | 235.11 |
| 1937 | 36 | 340.50 | 576.50 | 356.00 | 536.00 | 416.50 | 122.00 | 492.50 | 513.50 | 475.50 | | 3829.00 | 106.36 |
| 1938 | 36 | 507.00 | 700.50 | 647.00 | 742.00 | 638.50 | 720.50 | 707.50 | 954.75 | 728.50 | | 6346.25 | 176.28 |
| 1939 | 40 | A.F.B. | 185.50 | 190.50 | 299.00 | 175.50 | 260.50 | 314.50 | 196.00 | 201.00 | 252.00 | 2074.50 | 51.86 |
| 1940* | 40 | 61.00 | 206.50 | 211.00 | 247.50 | 235.50 | 178.00 | 209.00 | 311.50 | 342.50 | 278.00 | 2280.50 | 57.01 |
| 1941 | 40 | 755.00 | 575.00 | 863.00 | 952.50 | 560.50 | 396.50 | 478.00 | 636.50 | 680.00 | 489.00 | 6386.00 | 159.65 |
| Total | 248 | 3088.75 | 3314.25 | 3674.00 | 4199.50 | 3488.25 | 2751.00 | 3070.00 | 3456.25 | 3156.50 | 1019.00 | 31217.50 | |
| Average | | 110.31 | 118.36 | 131.21 | 149.98 | 124.58 | 114.62 | 127.92 | 144.01 | 131.52 | 84.92 | 125.88 | |

* All colonies hived on frames of foundation and fed sugar syrup. All supers contained only frames of foundation.

Table 3 indicates that supersedure has taken place in every one of the 10 methods in the experiment. There is considerable variation per method in any one year and for the same method over a period of years; e.g., in methods F and C.

## SUPPLEMENTARY INFORMATION

*Package Bee Questionnaire*

In 1936 there were forwarded 103 questionnaires to representative registered beekeepers in the province of Manitoba to ascertain the

TABLE 4.—QUESTIONNAIRE RESULTS ARRANGED ACCORDING TO SHIPPERS OF PACKAGE BEES

| Shipper's number | Number of shipments made | Number of packages shipped | Number of queens lost on introduction | Number of queens superseded | Percentage of queens lost on introduction | Percentage of queens lost through supersedure |
|---|---|---|---|---|---|---|
| 1 | 4 | 33 | 1 | 0 | 3.0 | 0.0 |
| 2 | 4 | 15 | 0 | 1 | 0.0 | 6.6 |
| 3 | 33 | 510 | 37 | 93 | 7.2 | 18.2 |
| 4 | 2 | 41 | 1 | 0 | 2.4 | 0.0 |
| 5 | 10 | 852 | 32 | 252 | 3.7 | 29.6 |
| 6 | 9 | 69 | 2 | 6 | 2.9 | 8.7 |
| 7 | 3 | 755 | 10 | 89 | 1.3 | 11.8 |
| 8 | 1 | 5 | 0 | 3 | 0.0 | 6.0 |
| 9 | 2 | 5 | 0 | 0 | 0.0 | 0.0 |
| 10 | 1 | 30 | 7 | 18 | 23.3 | 60.0 |
| 11 | 1 | 6 | 0 | 0 | 0.0 | 0.0 |
| 12 | 2 | 18 | 1 | 1 | 5.5 | 5.5 |
| 13 | 15 | 67 | 3 | 6 | 4.5 | 8.9 |
| 14 | 1 | 4 | 0 | 0 | 0.0 | 0.0 |
| 15 | 1 | 12 | 1 | 0 | 8.3 | 0.0 |
| 16 | 1 | 9 | 1 | 2 | 11.1 | 22.2 |
| 17 | 8 | 716 | 9 | 74 | 1.4 | 10.1 |
| 18 | 17 | 686 | 52 | 159 | 7.6 | 23.2 |
| 19 | 1 | 1 | 0 | 1 | 0.0 | 100.0 |
| 20 | 8 | 269 | 9 | 70 | 3.3 | 26.0 |
| 21 | 3 | 78 | 2 | 21 | 2.5 | 26.9 |
| 22 | 1 | 11 | 1 | 0 | 9.1 | 0.0 |
| 23 | 3 | 118 | 6 | 18 | 5.1 | 15.2 |
| 24 | 1 | 2 | 0 | 2 | 0.0 | 100.0 |
| 25 | 5 | 41 | 2 | 3 | 4.9 | 7.3 |
| 26 | 2 | 87 | 8 | 16 | 9.2 | 18.4 |
| 27 | 2 | 8 | 0 | 0 | 0.0 | 0.0 |
| 28 | 5 | 74 | 4 | 28 | 5.4 | 37.8 |
| 29 | 1 | 11 | 5 | 6 | 45.4 | 54.5 |
| 30 | 2 | 7 | 0 | 1 | 0.0 | 14.3 |
| 31 | 20 | 353 | 36 | 73 | 10.2 | 20.7 |
| 32 | 1 | 22 | 3 | 4 | 13.6 | 18.2 |
| 33 | 11 | 810 | 39 | 170 | 4.8 | 21.0 |
| 34 | 1 | 5 | 0 | 0 | 0.0 | 0.0 |
| 35 | 1 | 5 | 4 | 1 | 80.0 | 20.0 |
| 36 | 4 | 13 | 0 | 0 | 0.0 | 0.0 |
| 37 | 1 | 12 | 1 | 2 | 8.3 | 16.6 |
| 38 | 1 | 50 | 4 | 45 | 8.0 | 90.0 |
| 39 | 34 | 1223 | 70 | 127 | 5.7 | 10.4 |
| 40 | 1 | 16 | 0 | 0 | 0.0 | 0.0 |
| 41 | 2 | 3 | 0 | 0 | 0.0 | 0.0 |
| 42 | 1 | 24 | 4 | 1 | 16.6 | 4.2 |
| 43 | 1 | 1 | 0 | 1 | 0.0 | 100.0 |
| 44 | 4 | 7 | 0 | 1 | 0.0 | 14.2 |
| 45 | 4 | 118 | 6 | 29 | 5.1 | 24.6 |
| 46 | 1 | 2 | 0 | 1 | 0.0 | 50.0 |
| 47 | 1 | 22 | 0 | 7 | 0.0 | 31.8 |
| 48 | 3 | 30 | 9 | 4 | 30.0 | 13.3 |
| 49 | 27 | 478 | 52 | 82 | 10.9 | 17.1 |
| | 268 | 7734 | 422 | 1418 | 5.4 | 18.3 |

percentage of supersedure which they were experiencing in imported package bee queens; 48 replies, representing 1857 packages, indicated that supersedure of queens was taking place in 9.06% of the package colonies. A much more comprehensive questionnaire was outlined and forwarded to 4000 registered beekeepers in the province in 1937. This questionnaire called for information relative to the source of the package bees, date of arrival, treatment after arrival, whether the queens in the packages were attended by worker bees or alone (unattended) in the queen cages, preparations of the hive, installation of the packages, releasing of the queens, how soon the colonies were examined after the packages were hived, the number of queens lost on introduction, and the loss of queens through supersedure. Of the 357 replies received, 73.4% had purchased package bees. Approximately 22%, or 7734 of the total packages imported into the province of Manitoba in 1937, were accounted for in the replies to the questionnaire. Tables 4 to 7 outline the compiled results from the questionnaires.

TABLE 5.—QUESTIONNAIRE RESULTS ARRANGED ACCORDING TO STATES OR PROVINCES

| Name of State or Province | Number of shipments made | Number of packages shipped | Number of queens lost on introduction | Number of queens superseded | Percentage of queens lost on introduction | Percentage of queens lost through supersedure |
|---|---|---|---|---|---|---|
| Alabama | 81 | 2111 | 93 | 372 | 4.4 | 17.62 |
| California | 4 | 7 | 0 | 1 | 0.0 | 14.28 |
| Georgia | 5 | 37 | 13 | 7 | 35.1 | 18.92 |
| Louisiana | 43 | 2413 | 127 | 627 | 5.3 | 25.98 |
| Manitoba* | 36 | 171 | 6 | 11 | 3.5 | 6.43 |
| Mississippi | 61 | 1754 | 121 | 244 | 6.9 | 13.91 |
| Texas | 11 | 763 | 10 | 74 | 1.3 | 9.70 |
| Unidentified | 27 | 478 | 52 | 82 | 10.9 | 17.15 |
| | 268 | 7734 | 422 | 1418 | 5.4 | 18.33 |

* Manitoba agents ordered packages from southern shippers and distributed same within the Province.

TABLE 6.—QUESTIONNAIRE RESULTS GROUPED ACCORDING TO NUMBER OF PACKAGES IN SHIPMENT

| Grouping according to size of shipment | Number of shipments made | Number of packages shipped | Number of queens lost on introduction | Number of queens superseded | Percentage of queens lost on introduction | Percentage of queens lost through supersedure |
|---|---|---|---|---|---|---|
| 1 – 5 | 105 | 290 | 21 | 55 | 7.2 | 18.96 |
| 6 – 10 | 44 | 363 | 33 | 48 | 9.1 | 13.22 |
| 11 – 25 | 54 | 940 | 82 | 166 | 8.7 | 17.66 |
| 26 – 50 | 35 | 1407 | 99 | 261 | 7.0 | 18.55 |
| 51 – 75 | 10 | 618 | 36 | 125 | 5.8 | 20.23 |
| 76 – 100 | 6 | 521 | 24 | 77 | 4.6 | 14.78 |
| 101 – 200 | 9 | 1471 | 104 | 403 | 7.1 | 27.39 |
| 201 and up | 5 | 2124 | 23 | 283 | 1.1 | 13.32 |
| | 268 | 7734 | 422 | 1418 | 5.4 | 18.33 |

TABLE 7.—QUESTIONNAIRE RESULTS BASED ON QUEENS ATTENDED OR UNATTENDED

| Queens in queen cage | Number of shipments made | Number of packages shipped | Number of queens lost on introduction | Number queens superseded | Percentage of queens lost on introduction | Percentage of queens lost through supersedure |
|---|---|---|---|---|---|---|
| Attended with workers | 168 | 5236 | 276 | 924 | 5.3 | 17.65 |
| Unattended with workers | 73 | 2053 | 128 | 408 | 6.2 | 19.87 |
| Not Classified | 27 | 445 | 18 | 86 | 4.0 | 19.32 |
| | 268 | 7734 | 422 | 1418 | 5.4 | 18.33 |

The data in Tables 4 to 7 shows little or no connection between source of the bees or size of the shipment and incidence of supersedure, and the same applies to attended or unattended queens. A careful study of the replies to the remaining questions asked in the questionnaire also indicates that date of arrival has little or no effect on supersedure, nor the manner in which they are handled when received by the northern beekeeper. This final factor is particularly emphasized when the data on supersedure among over-wintered and home-reared queens are taken into consideration.

## SUPERSEDURE AMONG OVER-WINTERED QUEENS

Early in the course of the package bee experiment, it was considered pertinent to obtain information on the incidence of supersedure among over-wintered queens particularly to ascertain whether the supersedure impulse was more predominant in package bees than in over-wintered colonies. Painted queens heading colonies at the end of the season were prepared for winter; additional queens, about which supersedure records had been kept throughout the summer, but which were not directly under the supersedure experiment, were over-wintered.

TABLE 8.—SUPERSEDURE OF QUEENS IN OVER-WINTERED COLONIES

| Year | Number of queens in experiment | Number of queens superseded the following year | Number of queens in supersedure experiment the year previous | Number of queens superseded in their second year of production |
|---|---|---|---|---|
| 1936 | 47 | 16 | 14 | 5 |
| 1937 | 65 | 20 | 32 | 6 |
| 1938 | 68 | 15 | 28 | 4 |
| 1941 | 59 | 5 | 41 | 2 |
| Total | 239 | 56 (23.4%) | 115 | 17 (14.8%) |

Table 8 only gives a brief summary of the results obtained. Therefore to clarify the type of information obtained, the results of supersedure among over-wintered queens for the year 1938 will be outlined in detail. Records

of 68 queens successfully wintered were available; 12 of these queens had been introduced to colonies during the summer and fall of 1936; the remaining 56 queens had been introduced during the season 1937. Fifteen of the 68 queens were superseded during the summer of 1938; five of these were from the 1936 introductions, and 10 from the 1937 introductions. Twelve of the remaining 53 queens were replaced for the following reasons: 3 queens were drone layers in the spring; 1 queen was killed while a colony was being robbed in early spring; another queen was lost on introduction in a transfer to a nuclei; 1 queen was accidentally squashed and killed between two broodchambers; 2 queens were lost through swarming from congested nuclei; and 4 queens were replaced due to an apparent weakness which affected their egg laying capacity and the consequent poor building-up of the colonies which they headed. Forty-one of the remaining queens were not superseded before September 9, 1938.

Out of the 28 original queens successfully wintered and which were heading colonies in the "Supersedure of Queens in Package Bees Experiment" in 1937, four queens superseded; 1 in May, 1 in July, and 2 in August. Two of the additional queens became drone layers in spring, 1 queen was killed while the colony was being robbed, and the remaining 21 queens did not supersede during the 1938 season. Five 1937 package colonies in which the queens had been superseded or replaced wintered successfully. Three out of these 5 queens were superseded in 1938; one in June (queen had right hind leg paralyzed), 1 in July, and the third in August. A fourth queen, with her right hind leg paralyzed, had to be replaced in June and the fifth of these queens was lost on transfer to a nuclei in the spring. From 35 queens, heading over-wintered colonies, 8 queens were superseded; 1 was a drone layer in spring, and 7 queens had to be replaced. Four of these 8 superseded queens were introduced in 1936; 1 in July, and 3 in August. The July introduced queen was superseded in July 1938. Out of the 3 August 1936 introductions 1 queen was superseded in July and 2 in August 1938. The remaining 4, out of the 8 queens superseded, were introduced in August 1937. One of these 4 queens was superseded in July, 2 in August, and 1 in September 1938.

On the basis of the "Date of Introduction", the following figures are of interest. *1936 Introductions*—Out of the 3 queens introduced in July, 1936, one queen superseded in July, 1938; from 9 queens introduced in August, 4 superseded, 1 in June, 1 in July, and 2 in August, 1938. One queen, in addition to the August superseded queens, became a drone layer in the spring of 1938. *1937 Introductions*—From 29 queens introduced in May, 1937, one was superseded in May, 1 in July, and 2 in August, 1938. Two additional May introduced queens became drone layers and 1 queen was killed when a colony was robbed out in the spring. No supersedure took place in the case of the 1 queen introduced in July. Out of the 25 queens introduced in August, 1937, two were superseded in June, 2 in July, 3 in August, and 1 in September, 1938. Five additional of these queens had to be replaced for reasons other than supersedure. The one September 1937 introduced queen was lost on transfer to a nuclei in the spring of 1938.

In the 1937 report, it was intimated that more home-reared queens would be wintered-over, to determine whether the source of the queens

affected supersedure results to any extent. Nineteen home-reared queens were wintered-over. In the majority of the colonies these queens had been reared within the colony and had not been handled by human hands. These home-reared queens were to be compared with queens reared and shipped in from Alabama, California, and Ontario. Nine of the 19 home-reared queens were mated in 1936, 3 in July, and 6 in August; of the July queens, 1 superseded in July and 2 queens had to be replaced in July and August, 1938; three of the August 1936 mated queens were superseded, 1 in July and 2 in August, and one additional queen became a drone layer in the spring of 1938. The remaining 10 home-reared queens were mated; 1 in July, 8 in August, and 1 in September 1937. The July introduced queen did not supersede; 2 of the August mated queens superseded, 1 in June (queen injured) and 1 in August; the September mated queen was lost on introduction to a nuclei in the spring of 1938. Six of the nineteen home-reared queens superseded. Of the 3 California queens introduced in May 1937, one queen was killed in the robbing of the colony in the spring, 1 queen became a drone layer, and the third queen did not supersede. Although introduced in May 1937, these California queens had been reared and mated in the fall of 1936, wintered-over, and shipped north with package bees the following spring. Six queens were obtained from the Dominion Experimental Station, Kapuskasing, Ontario; 3 of these were introduced in August 1936, and 3 in August 1937. Of the 1936 introduced queens, 1 queen superseded in June (queen injured by bees), One of the queens introduced in 1937 superseded September 1, and 1 queen was lost in a swarm from a nuclei. Forty queens were imported from Alabama; 26 of these were introduced in May and 14 in August 1937. Of the 26 May introductions, 4 queens superseded; 1 in May, 1 in July, and 2 in August, and 1 additional queen turned into a drone layer in spring. The remaining 21 queens did not supersede. Of the 14 August introductions; 3 queens superseded, 1 in July, 2 in August; 2 queens had to be replaced in June; and the remaining 9 did not supersede during the 1938 season. On the basis of percentage supersedure, none of the 3 California-bred queens superseded, 17.5% of the Alabama-bred, 31.5% of the home-reared, and 33% of the Ontario-bred queens were superseded. The smaller number of queens received from California and Ontario may not be a fair comparison but the comparison between the Alabama-bred and the home-reared queens would indicate that caging, shipping, and introduction methods of southern-bred queens is not as vital a factor in supersedure as presupposed by many purchasers of southern package bees and queens. Table 9 outlines the data on the source of queens for the years 1936 to 1938 inclusive.

TABLE 9.—SOURCE OF QUEENS

| Year | 1936 | | 1937 | | 1938 | |
|---|---|---|---|---|---|---|
| Place of origin | Number of queens introduced | Number of queens superseded | Number of queens introduced | Number of queens superseded | Number of queens introduced | Number of queens superseded |
| Alabama | 27 | 9 | 39 | 15 | 40 | 7 |
| Ontario | 9 | 2 | 8 | 4 | 6 | 2 |
| Home-reared | 11 | 6 | 15 | 1 | 19 | 6 |
| California (Fall reared) | | | 4 | 0 | 3 | 0 |

## SUMMARY

The various methods used in the experiment involved the removal of the package bees from the cages by shaking them into or outside of the hive or allowing the majority of the bees to crawl out of the cages on to the combs. Frames of emerging brood were added at hiving time or 3 weeks later. Food, in varying type and quantity, including honey, pollen and sugar syrup were used. The quantity and type of comb were varied between foundation and drawn comb. The methods of releasing the queens involved attended or unattended queens in mailing or dry type of cages, with or without candy; running the queens in at the entrance, dipping them in sugar syrup and/or running them directly among a group of shaken package bees; receiving the queens by mail instead of in the packages; use of a special pollen candy. Clipping and painting the queens was performed 3 weeks after introduction of the package bees. Manipulation and management were indentical for all the methods throughout the experiment. Supersedure, in varying degrees, was evident in all of the 10 methods under experiment. Supplementary information, obtained by questionnaire survey, indicated little or no connection between source of the bees, the number of packages in a shipment, the date of arrival, or the manner in which the packages were handled after arrival and supersedure. A study of the problem of supersedure among over-wintered, home-reared queens showed as high or higher percentage of supersedure among this group as compared to queens shipped in from southern or Ontario breeders. The only difference that existed was that in the over-wintered colonies the supersedure process rarely interfered with colony morale or production, whereas in package colonies supersedure shortly after installation would frequently cause the production factor of that unit to be reduced to zero. Supersedure may only be reduced or eliminated through a controlled selective queen breeding program.

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# TRANSMISSIBLE "TWISTED LEAF" OF SWEET CHERRY[1]

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In 1938, two cherry trees in a commercial orchard were observed to be much smaller than other trees of the same age and to have leaf symptoms that had not been previously encountered. The name "twisted leaf" is suggested for the disease now that transmission has been obtained.

## OCCURRENCE

Orchard surveys in the Okanagan valley between 1938 and 1941 included slightly more than 9000 trees. Nearly all these trees were varieties of sweet cherry. The symptoms of "twisted leaf" were found in 13 trees in 7 widely-separated orchards; 5 trees showed marked symptoms in almost all the leaves and were badly stunted. Other trees were less seriously affected. One tree has consistently shown definite symptoms in scattered leaves with very little effect on the growth or vigour of the tree. The symptoms of "twisted leaf" have been found alone and also in conjunction with the symptoms of other diseases. They were observed in one tree together with the symptoms of a mild form of mottle leaf. In one orchard "twisted leaf" was found in 5 trees while all of these trees and many others showed the symptoms of a ring spot disease. All of the affected trees were of the Bing variety except one, a Black Republican.

## SYMPTOMS

There are three definite symptoms (Figure 1) that have consistently appeared on the leaves of affected trees. They are evident throughout the season. All three symptoms do not necessarily appear in every leaf but the combination of these three symptoms is not known to occur in any other disease. Other symptoms are either less consistently observed or are more readily confused with those of other diseases.

### 1. *Bilateral inequality*

In some leaves the part of the leaf on one side of the midrib is larger and more normal in appearance than the part of the leaf on the other side of the midrib. The smaller side tends to be more chlorotic, with slightly more acute angles between the midrib and the veins, and with more up-and-down waving of the leaf margin. The midrib is occasionally almost straight but it is usually smoothly curved in the plane of the leaf.

### 2. *Distortion*

In some leaves the distal portion is abruptly bent downwards. The abruptness of the bend is most noticeable on the midrib and least evident at the margin of the leaf. The extent of the bend may be slight or it may exceed a right angle. Similar bends occur at the union of the blade and

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petiole or part way down the petiole. The petioles are variously bent and twisted. The leaf margins frequently show a pronounced up-and-down wave and are occasionally buckled.

3. *Necrosis*

A bend is usually associated with necrosis of part of the midrib. This may be confined to the lower surface of the vein or it may occur on one or both sides. When necrosis extends through to the upper surface a portion of the midrib is likely to fall out of the leaf. Small parts of the lateral veins are similarly involved. Necrosis of the petiole is usually more superficial than that of the midrib. The bark appears normal and the death of shoots or spurs is not associated with this disease.

4. *Other Symptoms*

Some other symptoms are also found. In all trees the affected leaves are smaller than normal ones. Trees that are severely affected show symptoms that have not been observed in trees that are only slightly affected. They are stunted and the internodes are shortened particularly on the lateral branches. Rather severe defoliation from the base has been sometimes observed. Tufts or clusters of leaves are found. Many of these leaves have blades less than 2 inches in length. Mottling of two kinds occurs. The more frequent is a peppering of small yellow spots which usually have minute brown centres. The less frequent consists of short rather bright yellow lines close beside some of the lateral veins. The crop may be reduced and the fruit may be poor but no striking fruit symptoms have been observed.

FIGURE 1. Leaves of a Bing cherry tree infected with "twisted leaf".

## EXPERIMENTAL WORK

"Twisted leaf" has now been transmitted to all of the 9 young Bing trees that have been budded or grafted with material from infected trees. These transmissions include 6 primary transfers from 6 orchard trees and

3 secondary transfers from 2 of the experimental trees. Three of the primary transfers will not be discussed further because of the presence of the symptoms of other transmissible diseases. The other 3 naturally infected trees did not show the symptoms of any other transmissible disease. In September 1938, buds were collected from the 2 trees in which the disease had been first observed. These were budded onto 2 young Bing trees. "Twisted leaf" began to appear throughout both young trees in the early summer of the next year. One primary transfer produced a severe check in the growth of the young tree which has since made a slight recovery. Two secondary transfers from this tree have consistently shown a distinctly milder form of the disease. The second primary transfer produced a milder form of the disease than did the first. A single secondary transfer in this case resulted in definite transmission but with negligible effect on the growth of the young tree. The third primary transfer was made from a naturally infected tree which has consistently shown "twisted leaf" but only in scattered leaves. Transmission became evident in June in a young tree that had been grafted in April. This is the shortest time in which transmission has been obtained but the resulting disease was extremely mild.

## SUMMARY

1. A new transmissible disease of sweet cherry is described.

2. The disease has occurred in different degrees of severity in a few widely-separated orchards.

3. Transmission has been easily obtained by budding and grafting. Symptoms have appeared in two months or more.

4. Transmission has resulted in milder forms of the disease.

## BOOK REVIEW

WEED CONTROL. By Wilfred W. Robbins, Alden S. Crafts and Richard N. Raynor. XI 543 pages, 202 charts and illustrations. Published by the McGraw-Hill Book Company Inc., New York and London, 1942. $5.00.

This is the first published attempt to deal comprehensively with the general problem of weed control. A biological background to weed problems is provided in the first three chapters, which deal mainly with ecological questions, such as introduced and native species, reproduction, habitats and associations with useful plants. Various estimates of losses are also reviewed.

Roughly half the book is devoted to chemical methods of control. This may be explained, though not entirely justified, by the fact that the authors are all botanists at Davis, Cal., a well known centre of experimental work on herbicides. The most serious weakness in this part of the book, a defect so common as to be almost characteristic of textbooks, is that it deals very fully with one side only of a subject which is definitely controversial. The unwary student (or professor!) may be led to adopt the principle of "translocated herbicides" as an established reality. The suggested *modus operandi* at the present stage of our knowledge is more difficult to accept as a full solution of the matter even than the principle itself. It involves the assumption that "translocated herbicides" when applied to foliage, may be "sucked" into the roots by virtue of reduced atmospheric pressure in the xylem when soil moisture is low and the plants are near the wilting point. The evidence, in support of this view, is at present unconvincing, and in this connection Professor T. K. Pavlychenko's paper, elsewhere in this issue of *Scientific Agriculture*, is significant. Further, it is unfortunate that the admirable work on chemical control of field bindweed, administered by the Kansas State Board of Agriculture, is not given the space it merits.

The last four chapters deal with special weed problems and special weeds. To residents of the Northwestern prairies, the omission of *Achillea millefolium* from discussions of golf green and lawn weeds, and *Artemisia frigida* from the subject of over-grazed pastures will be regretted.

Notwithstanding the above criticisms, the book will prove very useful to all concerned with combatting weeds. Certainly nowhere else is such a mass of information, including extensive bibliographies, available. Chapter IV, dealing with methods of prevention, is well managed, but might with advantage be expanded. Only 15 pages are allowed Chapter VI, "Tillage Methods of Weed Control". If enlargement of the book were impossible, a few of the 250 pages given over to herbicides might have been borrowed. In this connection, a chapter dealing with problems of tillage in relation to combined weed and soil erosion control would have added greatly to the value of the book.

Probably we have been guilty of the very errors criticized, and over-weighted defects at the expense of merits. The book is full of interest and will be extremely useful.

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